A TREATISE

ON

ROADS AND PAVEMENTS.

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PREFACE.

THE object of this book is to give a discussion from the point of view of an engineer of the principles involved in the construction of country roads and of city pavements. The attempt has been made to show that the science of road making and maintenance is based upon well-established elementary principles, and that the art depends upon correct reasoning from the principles rather than in attempting to follow rules or methods of construction. In some cases practical experience has not yet determined the best method of procedure, and in these cases the conflicting views with the reasons for each are fully stated.

Considerable space has been given to the economics and location of country roads and to the construction and maintenance of earth roads, since such roads constitute more than ninety-five per cent of the mileage of the public highways and are greatly in need of careful consideration. It is frequently claimed by engineers that the public would be benefited by placing the care of the roads in the hands of engineers; but there is no evidence that any considerable number of engineers comprehend either the principles of road making necessary for the improvement and maintenance of our country roads, or the economic limitations and political difficulties of the problem. The first four chapters of this book are offered as a contribution to this phase of the good-road problem.

The remainder of the book, the portion that considers roads having permanently hard surfaces, which may not unfittingly be said to relate to urban and suburban roads, is based chiefly upon American experience, because the principles of road making worked out in this country are probably best suited to American conditions, and also because in most particulars American roads and pavements are superior to any other in the world. Some countries

have more hard roads than this, because of a difference in conditions; but in no country does the quality of such roads average better than in this. In some foreign cities the pavements seem to be better cared for than in this country, owing chiefly to different controlling conditions; but the principles of construction employed here are equal to the best. Notwithstanding the general excellence of the best American practice in constructing hard roads and pavements, there is still room for improvement in adapting the particular form of construction to the local conditions and also in preserving the surface from ruthless destruction. These two phases of the subject have been emphasized in the proper places in this volume. Throughout the attempt has been to state fully and clearly the fundamental principles of the construction and maintenance of roads and pavements.

In the preparation of the book the endeavor has been to observe a logical order and a due proportion between the different parts; and great care has been taken in classifying and arranging the matter. It will be helpful to the reader to notice that the volume is divided successively into parts, chapters, articles, sections having small-capital black-face side-heads, sections having lower-case black-face side-heads, sections having lower-case italic side-heads, and sections having simply the serial number. In some cases the major subdivisions of the sections are indicated by small numerals. The constant aim has been to present the subject clearly and concisely.

Every precaution has been taken to present the work in a form for convenient practical use and ready reference. Numerous cross references are given by section number; and whenever a table or a figure is mentioned, the citation is accompanied by the number of the page on which it may be found. The table of contents shows the general scope of the book; the running title assists in finding the different parts; and a very full index makes everything in the book easy of access.

The author will esteem it a favor if any errors that may be found are at once brought to his notice.

I. O. B.

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ROADS AND PAVEMENTS.

INTRODUCTION.

THE problems involved in the construction and maintenance of rural highways differ materially from those which are encountered in the improvement and care of city streets, and therefore this discussion of the subject of Roads and Pavements will be divided into Part I, Country Roads, and Part II, City Pavements. In each division of the subject certain general principles will first be considered, and the further discussion will be divided according to the several materials in use for the road surface. It will not always be possible to keep the several portions entirely distinct, but a knowledge of the intention in this respect will make it easier to understand the method of presentation or to turn readily to the discussion of any particular phase of the subject.

PART I.

COUNTRY ROADS.

PART I will include matters relating to earth, gravel, and broken-stone roads in rural districts, although some of the discussion is also applicable to these road surfaces when employed in city streets.

CHAPTER I.

ROAD ECONOMICS.

1. **ADVANTAGES OF GOOD ROADS.** Good roads are so important in the financial, social and educational well-being of a rural community that no enumeration of their advantages is likely to include all the benefits; but a brief consideration of some of the chief advantages of good roads will be of value in determining the amount of money that may justifiably be expended to secure road improvement and in deciding what classes should in equity bear this expense. The principal advantages of good roads, i. e., of permanently hard ones, are as follows:

1. Good roads decrease the cost of transportation,—at some seasons of the year considerably, but at others only a little. This item will be considered more fully later (see § 4–9).

2. Good roads permit the cultivation of crops not otherwise marketable. This advantage results in extending the area devoted to the cultivation of fruits and vegetables, and is most effective in the vicinity of a large city.

3. Good roads give a wider choice of time for the marketing of crops. In some instances good roads permit the crops to be mar-

keted when the labor of production is less pressing; but this advantage accrues only to the producers of imperishable crops, and is not of great importance, since the labor required to market the product is small in comparison with that of production.

4. Good roads permit the marketing to be done when the prices are most favorable. This advantage is more important with perishable than with imperishable products. As far as perishable products are concerned, this advantage is virtually included in paragraph 2 above. As far as imperishable products are concerned, this advantage is important only near a large city, i. e., where the producer sells directly to the consumer. Prices of staple farm products (not garden products) are not much affected by roads, since the condition of the roads is local while prices are governed by world-wide conditions. Writers on good-road economics usually greatly overestimate this advantage as far as the ordinary producer of imperishable products is concerned. If this advantage were anything like as great as is frequently claimed. producers would store such products at the local shipping point, or in the great city, or at the port of export, awaiting a favorable price. Such storage would also permit the delivery at a time when other work was least pressing. The expense of storage at the local shipping point is a small per cent of the value of the product. It is frequently, but erroneously, claimed that hard roads would save the Illinois farmer 3 to 5 cents per bushel—an amount 10 to 15 times the cost of the storage. Since producers do not so store their products, it is safe to assume that this advantage of good roads as a rule is not very great. The present method of doing business makes this advantage comparatively unimportant.

5. Good roads give a wider choice of the market place. This advantage affects perishable products chiefly, and for geographical reasons is, as a rule, not very great.

6. Good roads tend to equalize the produce market between different climatic conditions. In the absence of railroad transportation and cold storage, this advantage might be of considerable local importance; but under ordinary conditions it is comparatively unimportant.

7. Good roads tend to equalize railroad traffic between the different seasons of the year. Impassable wagon roads over any

considerable area materially decrease the amount of agricultural products to be transported by railroads, and a return of good roads will for a time congest the railroad transportation facilities. The effect of good roads in equalizing railroad transportation is partially neutralized by the fact that agricultural products are only one of many classes of commodities transported by the railroads; and also by the fact that most railroads transport agricultural products originating over a considerable area, and bad wagon roads are not likely to occur all over the contributory area at the same time; and further by the fact that the storage capacity of warehouses helps to equalize the traffic.

8. Good roads tend to equalize mercantile business between different seasons of the year. Merchants having a considerable rural custom could do business more economically if the trade were distributed uniformly throughout the year. However, the succession of good and bad wagon roads is only one cause of the unequal distribution of rural patronage.

9. Good roads permit more easy intercourse between the members of rural communities, and also between rural and urban populations. This is an important benefit, particularly in a republican form of government.

10. Good roads facilitate the consolidation of rural schools, and thereby increase their economy and efficiency. This is an important matter to coming generations.

11. Good roads facilitate rural mail delivery, and thereby tend to improve the social and intellectual condition of the rural population.

12. Good roads sometimes change rural into suburban property, and sometimes are a material factor in inducing tourist travel and securing vacation residents.

2. It is customary to include the increase in the price of farming land as one of the benefits of good roads; but the increase in price of land is simply the measure of the value of all the above advantages, and hence should not be included.

3. Notice that the first eight advantages mentioned above relate to the financial benefits of hard roads, and the last four to the social benefits. In the past writers upon good-road economics have given much attention to the supposed financial benefit of hard roads and

little or none to the social advantage. Any considerable expenditure for the improvement of rural highways can not be justified on financial grounds alone (see § 9). Good roads are chiefly desirable for the same reason that a man buys a carriage or builds a fine house, i. e., because they are a comfort and a pleasure. Good roads are to be urged principally for the same reason that good schools are maintained, namely, because they increase the intelligence and value of the citizen to society.

4. COST OF WAGON TRANSPORTATION. The chief financial advantage of hard roads is the decreased cost of transportation. It is proposed to inquire briefly concerning the cost of wagon transportation with a view of determining the proportion of this cost that may be saved by road improvement.

In this connection, a distinction must be made between the cost to those whose chief business is to sell transportation, and the cost to those to whom transportation is a mere incident of a business organized for some other purpose. The first class is represented by a freighter, or a transportation company, and the second by a farmer or producer. The former maintains his teams and wagons only to transport freight, while ordinarily the latter keeps his teams and wagons primarily for general farm work of which transportation on the roads is only a small part. In some cases the traffic to be considered is principally that by freighters, but usually the chief traffic over country roads is that connected with agricultural operations.

Again, consideration should be given only to hauling in which the load is equal to the full capacity of the team for the particular condition of the roads. A farmer may employ a two-horse team to take a bushel of potatoes to town, or a grocery wagon may make a trip to deliver a pound of cheese; but the partial load is entirely independent of the condition of the roads.

Further, it is necessary to notice that only the rate for full loads should be considered. If a number of packages are carried in the same load for different parties, part of the charge is to cover the cost of collection, distribution, possible partial loads, etc.; and therefore only part of the charge is for transportation proper.

5. Cost to Freighters. The cost will vary greatly with the conditions of the service, i. e., with the character of the road

surface, the average grade of the road, the maximum grade, return load, etc.

Except in rare cases, the cost per ton-mile for loads one way upon earth roads will not be more than 25 cents, and ordinarily it will not be more than 15 to 20 cents; * while with easy grades and favorable road surface it may be as low as 10 to 15 cents, and with long hauls, return loads, and favorable road surface, it may be 8 to 10 cents. When the last price is obtained there is little need or opportunity for road improvement.

6. Cost to Farmers. In this division of the subject, a distinction should be made between producers of perishable products and producers of non-perishable products. The first class is represented by gardeners, dairymen, fruit-growers, etc.; and the second, by producers of hay, grain, cotton, etc.

The cost of transportation is much greater for perishable than for non-perishable products. In the first place, the marketing of perishable products is an unimportant factor in comparison with the cost of production, and frequently necessitates an independent transportation department; while the labor of marketing non-perishable products is comparatively small—particularly as in most localities where there is much of this class of produce, the distance from the farm to the railroad station is short. Further, perishable products must go to market whatever the condition of the roads, while non-perishable ones can wait for comparatively favorable conditions; and finally, the former frequently go to market in partial loads, and the second usually in full loads. Except in comparatively limited districts, non-perishable products make up the bulk of the traffic on the country roads. According to the U. S. Census of 1890, the gardeners, fruit-growers, dairymen, vine-growers, florists, and nurserymen constitute only 1.8 per cent of the so-called farming class.

7. The cost of transporting perishable products is probably greater than that for any other class of traffic over the country roads; but as it is next to impossible to secure any reliable data no attempt will be made to present any general conclusions. For

* See "Cost of Wagon Transportation," by the author, in Proceedings of Illinois Society of Engineers, Vol. 16, p. 36–44; full abstract of the same in *Engineering News*, Vol. 45, p. 86.

several reasons, this traffic will usually justify larger expense for road improvement than any other.

The cost of transportation to farmers proper, i. e., producers of non-perishable products, depends chiefly upon the condition of the road surface and upon the demands of general farm work. Loam or clay roads are reasonably good when dry, and are therefore at least passable most of the year; while sand roads are at their worst when dry, and are therefore in their worst condition during the greater part of the year. Fortunately sand roads are less common, the country over, than clay or loam roads. In the crop season, with a little choice as to the time of doing the work the cost on fairly level loam or clay roads is probably not more than 10 to 12 cents per ton-mile; and when farm work is not pressing, the cost is not more than 8 to 10 cents per ton-mile.*

8. A Conflicting View. In current literature on road economics, the claim is frequently made that the cost of wagon transportation to the farmer is considerably more than stated in § 6. Apparently most of these claims are based, either directly or indirectly, upon data published in Circular 19 of the Road Inquiry Office of the United States Department of Agriculture. As the general reliability of the data in that circular is discussed in § 13–19, and the part referring to cost of wagon transportation is considered in § 20–24, the matter will not be discussed here.

9. Financial Value of Road Improvement. It is not possible to present any valuable general conclusions as to the saving in cost of transportation attainable by any proposed road improvement.

For any particular road where the traffic is principally by "freighters" as defined in § 5, it is possible to arrive at a rough approximation by (1) taking a census of the traffic, (2) making an estimate of the present cost per ton-mile, and (3) making an estimate of the cost after the improvement. The amount of traffic varies with the condition of the road surface, and the chief difficulty is to determine the advantage of being able to move freight at any

* See "Cost of Wagon Transportation," by the author, in Proceedings of Illinois Society of Engineers, Vol. 16, p. 36–44; full abstract of the same in *Engineering News*, Vol. 45, p. 86.

time. This advantage will depend upon the proportion of the time that the roads are "good," which depends entirely upon the locality and the nature of the road surface, and varies greatly from year to year. Ordinarily the road is used by a variety of teamsters, and the cost varies with the particular circumstances of each. There will rarely be conditions to which this method of investigation can be applied with any degree of certainty. At best the results of such an investigation must be regarded as mere approximations, since no factor of the problem can be determined accurately, and since any slight error in the estimated saving per ton-mile is greatly magnified when multiplied by the number of ton-miles. Nevertheless such an investigation is desirable to aid the judgment, but its approximate nature should not be forgotten.

For roads where the traffic is by farmers the difficulties are still greater. The number of users is greater, the cost of transportation to the different users varies very greatly, and the value of being able to use the road at any time is very different with different users, and for the same class of users varies with the locality and the nature of the road.

The amount of money that may justifiably be expended for any proposed road improvement will depend upon the present condition of the road, the amount and the nature of the traffic, and the cost of constructing and maintaining the improved road. The question is a local one, and can be answered approximately correctly only after careful study of the conditions. Ordinarily the saving in transportation, except near large cities, will not justify any radical road improvement; but with a miscellaneous traffic, the social advantages of road improvement should be taken into consideration, even though they can not be computed in dollars and cents.

10. Estimated Cost of Bad Roads. Most of the current literature on good-road economics greatly exaggerates the financial advantage of road improvement. Three such estimates will be examined.

11. A Wild Guess. A favorite method of showing the wastefulness of bad roads is to compare the efficiency of horses on European and American roads. Some claim that a horse in Europe does twice as much work as in America, solely because of the better roads; while others claim that three horses in Europe do as much

as four in America. The annual cost of bad roads to the American farmer is then said to be the annual cost of feeding one quarter to one half of all the horses in America plus the annual interest on the value of the superfluous horses. The results are truly appalling.

In the first place, the premise is a mere guess, since it is impossible off-hand to state the relative efficiency of horses in Europe and in America.

In the second place, the above line of argument assumes that all horses are continuously upon the road. This assumption is seriously in error, since there are a large number of horses in the cities not in any way connected with the farms, and further since the horses on the farms include a number too young to work, and still further since most farmers require considerably more horses to raise the crops than to transport them to market.

2. A Rough Estimate. Another common method of demonstrating the cost of bad roads is to estimate the saving per horse due to improved roads. The annual saving per horse is variously estimated at from $10 to $20, and the saving in vehicles and harness is estimated as equivalent to $5 per horse, making a total annual saving by good roads of $15 to $25 per horse. This sum is then multiplied by the number of horses given in the census report or returned by the tax assessor, and the product is said to be the annual loss by the farmers due to bad roads. The result is startling.

No evidence is offered to show the actual loss by bad roads. Possibly a horse continually on the road could earn $10 to $20 per year more on good roads than on poor ones. But, on the contrary, farmers claim that the damage to a horse through continuously driving on "good roads," i. e., on stone roads, is more than $20 per annum. "The hard roads stiffen up a horse." The cost of keeping a horse shod is considerably more with stone than with earth roads. These losses due to permanently hard roads are reasonably certain, while the advantages claimed are problematic. Possibly the damage to harness is more with poor than with good roads; but farmers claim that vehicles wear out faster on stone than on earth roads. In short, the advantages are not all on one side, and the saving claimed is not proved.

Even though a horse continually on the road could and would earn $15 per annum more on good roads than on poor ones, the

above estimate is grossly in error, since only a small per cent of the horses are on the road all the time, or since the average horse is on the road only a very small part of the time. Unquestionably a horse can do more work on good roads than on poor ones, but that does not prove that farmers, gardeners, etc., as a rule, would require fewer horses with better roads or that their horses would earn more.

13. Statistical Results. Circular No. 19, published under date of April 4, 1896, by the Road Inquiry Office of the United States Department of Agriculture, contains data as to the cost of bad roads and the saving possible through road improvement. The conclusions of this circular have been so widely quoted and so generally accepted as to justify a careful consideration of them here. Table 1 is from that circular.

TABLE 1.

DATA ON COST OF WAGON TRANSPORTATION.

Ref. No.	Locality.	Average Distance Hauled, Miles.	Average Load Hauled, Tons.	Average Cost per Ton-mile, Cents.	Total Cost from Farm to Market, per Ton.
1	Eastern States	5.9	1.108	32	$1.89
2	Northern States	6.9	....	27	1.86
3	Middle-Southern States......	8.8	....	31	2.72
4	Cotton States	12.6	0.688	25	3.05
5	Prairie States	8.8	1.204	22	1.94
6	Pacific Coast and Mountain	23.3	1.098	22	5.12
7	Whole United States	12.1	1.001	25	3.02

The author inquired of the Road Inquiry Office as to various details of the investigation, and in reply received the data in Table 2, page 12, with a statement that it contained all that was then known about the statistics.

14. *Elaborateness of the Investigation.* Owing to its seeming elaborateness, the above official investigation has carried great weight. The statement that ten thousand letters were sent out, apparently creates the conviction that the investigation was a very elaborate one; but the area to be covered was very great, and

TABLE 2.

DATA ON COST OF WAGON TRANSPORTATION BY STATES.

State.	Number of Counties Answering.	Average Haul, Miles.	Average Load, Pounds.	Cost per Ton-mile.	Average Cost per Ton.
Alabama	23	12.77	1 383	$ 0.25	$ 3.13
Arizona	1	60.00	2 000	.25	15.00
Arkansas	31	24.30	1 419	.21	5.16
California	20	10.9	2 480	.22	2.38
Colorado	23	10.5	2 417	.20	2.16
Connecticut	3	6.6	2 000	.34	2.25
Florida	25	7.5	1 246	.39	2.92
Georgia	63	8.8	1 382	.24	2.16
Idaho	8	24.5	2 325	.22	5.43
Illinois	56	5.5	2 250	.23	1.25
Indiana	42	4.6	2 272	.28	1.28
Iowa	44	5.4	2 071	.24	1.31
Kansas	52	9.3	2 420	.17	1.68
Kentucky	54	8.	1 995	.35	2.84
Louisiana	23	13.	1 443	.25	3.43
Maine	5	8.8	2 050	.24	2.10
Maryland	12	4.5	1 991	.29	1.29
Massachusetts	4	6.7	2 750	.33	2.75
Michigan	26	7.	1 874	.27	1.87
Minnesota	33	8.5	2 226	.21	1.82
Mississippi	35	14.3	1 268	.25	3.82
Missouri	49	9.	1 773	.22	1.90
Montana	15	14.5	2 400	.23	3.27
Nebraska	39	9.4	2 190	.21	1.83
New Hampshire	5	4.6	2 400	.31	1.45
New Jersey	8	4.	2 100	.38	1.53
New Mexico	7	34.	1 584	.20	6.93
New York	30	6.	2 220	.26	1.56
North Carolina	43	11.5	1 360	.24	2.62
North Dakota	22	13.	2 986	.18	2.07
Ohio	43	5.	2 193	.28	1.46
Oregon	14	10.	2 000	.33	3.34
Pennsylvania	25	6.6	2 036	.34	2.19
South Carolina	11	6.3	1 409	.25	1.81
South Dakota	23	11.8	2 330	.23	2.58
Tennessee	45	10.4	1 540	.25	2.63
Texas	74	18.	1 523	.17	3.16
Utah	14	38.	2 221	.14	5.48
Vermont	5	5.	2 200	.31	1.54
Virginia	42	9.	1 719	.29	2.65
Washington	18	7.7	2 350	.21	1.63
West Virginia	18	12.7	1 886	.40	5.00
Wisconsin	25	7.6	2 184	.26	1.93
Wyoming	3	40.	2 800	.11	4.50
United States	1 061	12.1	2 002	$ 0.25	$3.02

the inquiries average only one to 300 square miles,—or say about three inquiries to two counties. This shows that the attempt was not on a very elaborate scale.

The Circular says that Table 1 "represents the returns from about 1,200 counties"; while Table 2 shows that replies were received from 1,061 counties. The first is equivalent to about one county in twenty-five, and the second to about one in thirty. In either case, the number of answers was entirely inadequate to secure data representative of the entire country. It is stated by the Director of the Road Inquiry Office that "nothing is known as to the number of replies received from each county."

15. *Average Haul.* The value of the reply as to the average haul will depend upon the manner of determining it. "The Road Inquiry Office has no copy of the letter of inquiry." Apparently the letter merely asked for the average haul, and gave no instructions as to the method to be used in deducing it. A man on receiving such an inquiry and knowing that farm products were hauled to a certain town from all distances up to ten miles, would probably reply that the average haul was one half of 0+10, or 5 miles. By many trials, the writer has found that in the great majority of cases this answer is accepted as correct; while in fact it is erroneous, and in many cases greatly so. This method of determining the average haul does not take into account the number of loads hauled each distance. The average of the distances hauled is ordinarily considerably more than the average haul; and for this reason, it is probable that the values in the first column of Table 2 are considerably too great. The distance hauled will vary greatly with the locality. Farm products will be hauled much farther to a large city than to a small village; certain kinds of products will be hauled much farther than others; and the distance hauled will vary greatly with the kind of roads. The result for the average haul to large cities, where a considerable part of the freight traffic on the public highways is hauling vegetables, fruit, etc., over good stone-roads to market, even though correctly determined, is of but little value in finding the cost of hauling the average farm product to market. Gardeners, dairymen, etc., live chiefly near large cities and are more interested in good roads than the average farmer; therefore it is possible that the replies from near large cities were in undue pro-

portion. According to the U. S. Census for 1890, gardeners, dairymen, florists, nurserymen, and vine-growers constitute only one fifty-seventh of the so-called farming class; and the "area devoted to raising fruit and vegetables for market is 534,440 acres," or one six hundred and sixty-ninth of the area of the cultivated land.

The value of the replies in determining an average will depend upon their distribution with reference to productiveness. One part of the state furnishes more traffic and is better supplied with railroads than another. The replies should be distributed proportionately to the amount of traffic.

16. An examination of a large-scale railroad map of the United States indicates that probably the average haul as given in Table 2 is considerably too great—at least for the states that furnish the bulk of the traffic. Portions of a state may be found which are relatively at a considerable distance from a railroad station, but in nearly every case it will be found that throughout that area there is but little traffic on the public highways.

17. The reliability of the value of the average haul as given in Table 2 can be approximately tested in another way. For example, Illinois has an area of 56,600 square miles, and in 1895 had 10,752 miles of railways exclusive of sidings and second tracks; or 1 mile of railroad for each 5.2 square miles of area. Investigations also show that the distance between railroad stations averages a trifle under 4.5 miles. Therefore, if we consider a strip of land 5.2×1 miles laid transversely across the railroad half way between railroad stations, the maximum haul will then be approximately $\frac{1}{2}$ of $5.2 + \frac{1}{2}$ of $4.5 = 4.8$ miles. This may be regarded as the average maximum distance of haul in Illinois. The average haul is probably approximately half this, or say 2.4 miles. There is a slight error in the above computation, since no account is taken of the fact that the railroads cross each other or that they converge toward railroad centers; and for this reason the above result is slightly too small.

On the other hand, the above method is slightly in error since no account was taken of water transportation; and for this reason the above result is slightly too great. Again, the above result is slightly too small, since produce is hauled on wagon roads considerable distances to large cities; but the amount of these products is

small as compared with the total agricultural products (see § 23). Therefore we may conclude that the above result is not much too small, although it is less than half that in Table 2.

A similar investigation for Iowa, Eastern Kansas, Eastern Nebraska, Ohio, and Indiana, leads to the conclusion that the values for the average haul in Table 2 are about twice too great. The above method of testing the data in Table 2 is applicable to states that have considerable areas of untilled land, since under these circumstances the distribution of railroads and railroad stations will not be even approximately uniform.

18. The reliability of the data in Table 2 may be tested in another way. The Illinois Agricultural Experiment Station, in Bulletin No. 50, published the data received in 316 replies from 76 counties in Illinois concerning the cost of producing and marketing corn and oats. According to these data the average distance hauled was 3.2 miles—about six tenths of the value in Table 2 for the average haul in Illinois.

19. *Average Weight of Load.* The weight of the average load varies chiefly with the grade of the road and the condition of its surface; and in most localities the latter varies greatly with the season, and is not the same for any two successive years. Further, with earth roads (and they constitute the great majority of agricultural roads in this country) the most of the freight is hauled when the roads are in their best condition. For these reasons, it is a matter of considerable difficulty to determine the weight of the average load for any particular place, much less for an average of several states. However, as these data are not directly used in determining the supposed cost of bad roads, this phase of the subject will be discussed only briefly.

In the Bulletin just referred to the average load in marketing 311,845 bushels of corn was 62 bushels. If it were all shelled, this is equivalent to 1.74 tons per load; and if it were unshelled, it is equivalent at least to 2.2 tons per load. As part of it was shelled and part not, the average load in this case was somewhere between $1\frac{3}{4}$ and $2\frac{1}{4}$ tons.

20. *Cost per Ton-mile.* No details are given as to the method employed in determining the cost per ton-mile of hauling crops from farm to market. The value of the answer depends upon the

form of the inquiry. The author has frequently asked grain farmers: "What is it worth to haul crops to market?" In a great majority of cases the answer is arrived at by counting the price of a wagon, team, and driver at $3.00 or $3.50 per day (the current price for those whose chief business is to do teaming), and assuming that a team will travel about 3 miles per hour and haul a load of 1 to 1½ tons. The result by this method of computing the cost per ton-mile is substantially the same as that in Table 2. On changing the form of the question and asking: "What does it really cost you?", the answer is almost invariably: "Nothing." The average farmer is not conscious that it costs him anything to haul his crop to market. The great bulk of the hauling is done when the farmer has little or nothing to do, or when the delay of other work is a matter of little moment; and in this case the cost is merely nominal. The overlooking of this fact is a common and most serious error of writers on good-road economics.

The cost per ton-mile as given in Table 2 indicates that that value was obtained by assuming the wages of a wagon, team, and driver to be about 35 cents per hour; that the team travels about 3 miles per hour; and that the team hauls a load only one way. There are two radical errors in this method.

1. The price per day is too great. In the Bulletin referred to in § 18, the price per day for team and man during the crop season, as given by the farmers themselves, ranged from $1.40 to $2.74, the average for the 76 counties being $2.13. Notice that this is the average cost during the crop season, as returned by 316 farmers in 76 counties in Illinois. Evidently the price per day as returned by the same farmers for the dull season would be considerably less.

2. The mean between the maximum and the minimum load may be one ton; but the great bulk of teaming is done when the roads are at least in fair condition, when the load is considerably more than one ton. In fact, there is very little of the crop hauled to market when the load is one ton or less. The author has examined the records of several grain buyers in central Illinois, where at times the roads are as bad as anywhere, and finds that the average load is nearly a ton and a half. See § 19.

21. Non-resident land owners in central Illinois frequently hire corn delivered for 9 to 11 cents per ton-mile. This price has ob-

tained over large areas for 10 or 15 years. The contract is usually taken by the man who does the shelling, he hiring farmers to do the hauling. These prices obtain frequently during the corn-planting season, when the farmers are most busy and when the roads are certainly not at their best. During the dull season farmers frequently haul corn to the farther market for a difference in price equivalent to 6 to 9 cents per ton-mile for the hauling. The lower of these prices usually obtains when the roads are good in the winter season and there is little or no farm work to do. Notice that the above prices are practically one third of those given in Table 2 for Illinois.

The results in Table 2 for the cost per ton-mile may be approximately correct for gardeners, dairymen, etc., who are compelled to keep a team upon the road nearly every day of the year; but these are not representative "farmers," for, according to the Eleventh Census of the United States, there are 5,281,557 farmers and planters, and only 90,470 gardeners, dairymen, florists, nurserymen, and vine-growers; or, the latter constitute only one fifty-seventh of the agricultural class, and work only one six hundred and sixty-ninth part of the cultivated land.

22. The conclusion is that in Table 2 for Illinois the distance hauled is twice too great and the price per ton-mile is about three times too great; or the "total cost from farm to market" (see Table 1) is 2 × 3 or 6 times too great. Probably the values for the other states are equally in error.

23. *Cost of Marketing Crops.* Circular No. 19 of the U. S. Road Inquiry Office, previously referred to, determines that in 1895 the farm products amounted to 219,024,277 tons; and assumes that the farm products consumed on the farm are offset by the mine and quarry products, merchandise, etc., hauled over the public roads. It is further assumed that one quarter of the timber cut for fuel and for the mill, and all of that used by the railroad, or a total forest product of 93,525,000 tons, is transported over the public highways. The conclusion is that in 1895, 313,349.227 tons were hauled over the highways of the United States. The Circular assumes that the average cost of transporting this freight is $3.02 per ton (the average "cost from farm to market," see last line of Tables 1 and 2), and that therefore the cost of wagon transportation in 1895

was $946,314,665.54. "The immensity of this charge," to quote the Director of Road Inquiry, "will be best realized by comparing it with the value of all farm products in the United States for the year 1890—$2,480,170,454. In other words, the annual cost of the transportation upon the public highways of the United States is equal to 38 per cent of the value of the farm crops." Or, since 70 per cent of the freight is assumed to be farm products, according to the above data, the cost of hauling directly and indirectly connected with marketing the crops is $38 \times 70 = 26.6$ per cent of the value of these products. The total area of the farms in the United States is 975,000 square miles, and therefore the above cost of wagon transportation is $971 per square mile, or $1.51 per acre; or, if we include only the improved land, the above cost of wagon transportation is $1,700 per square mile, or $2.65 per acre.

The above conclusions are believed to be in error for the three following reasons:

1. The Circular assumes that the farm products consumed on the farm were offset by the hauling of lumber, coal, fertilizers, merchandise, etc., to the farm. In the first place, it is doubtful if there are as many tons of freight hauled to the farm as there are tons of products consumed on the farm. In the second place, the offset ought not to be allowed, since almost always the freight hauled to the farm is brought back when a load of produce is taken to town, or is hauled back incidental to a trip for some other purpose, or is hauled when there is nothing else to do. In the third place, a considerable part of the farm product is driven to market on foot.

2. The average haul for each of the several states is in error as discussed in § 15-18, and, in addition, the value for the United States is in error since no account has been taken of the relative amount of traffic in the several states. For example, Iowa, with its 5.4 miles haul and 25,000,000 tons of traffic, has no more weight in the mean than Arizona with a haul eleven times as great and a traffic only one hundredth as great. Again, no difference is made between Illinois, with 72 per cent of tillable land, and Wyoming, with only 1 per cent; and Delaware with an area of 2,050 square miles has the same weight as Texas with an area of 265,780 square miles.

3. The cost per ton-mile is too great for the reasons stated in § 20–22.

24. If the cost of hauling the crops to market were 26.6 per cent of the value of the crops, then there should be a marked difference in the price of land near and remote from market. If it costs 26 per cent of the value of the produce to get it to market, then land at the market should be worth at least 26 per cent more than land which is the average haul away from market. It should be worth more than this, for there is a considerable amount of travel involved besides that necessary to market the crop. An investigation in central Illinois, where the land is of uniform quality, shows that the price of land at the market is about 5 per cent more than that 5 miles away. In a rough way this shows that the estimates of Tables 1 and 2 are at least something like five or six times too great.

If the cost of hauling crops to market is equal to 26 per cent of their value, then there should be a marked difference in the rent of land. The annual rent of land varies from one quarter to one half the crop. If land the average haul from the market rents for one quarter of the crop, then land at the market should rent for half the crop, even if the social advantage of the latter is not included. In central Illinois, where at times the roads are as bad as anywhere, there is no appreciable difference in the renting value between land 1 mile and that 5 miles from market. This shows that the conclusions of the above Circular are greatly in error.*

25. Possible Annual Saving. The Office of Road Inquiry in Circular No. 19, to which reference has been made, estimates the possible annual saving by road improvement as two thirds of $943,314,665.54, or $628,000,000. This estimate is based upon a comparison of the data in Circular No. 19 with that on the "Cost of Hauling Farm Products to Market or Shipping Point in European Countries, Collected by U. S. Consular Agents," published in Circular No. 27 (Feb. 5, 1897) of the Office of Road Inquiry of the U. S. Department of Agriculture. The average cost as given in the latter

*For a further discussion of the Circular see the following: In defense of the Circular, *Engineering News*, Vol. 34, p. 410–11; do., Vol. 45, p. 50–51. Controverting the Circular: *Engineering News*, Vol. 34, p. 377–78; do., Vol. 34, p. 410–11; do., Vol. 44, p. 337–44; do., Vol. 45, p. 48–49.

circular (when translated) is 10 cents per ton-mile, and the difference between this and the average stated in Table 1 is 15 cents per ton-mile, which is two thirds of the average value in Table 1.

Concerning the data for America, notice that they are taken from Circular No. 19, and are greatly in error as has already been shown.

Concerning the data for Europe, notice in the first place that they are open to most of the criticisms made against the data in Table 2. In the second place, the twelve results given in Circular 27 vary from 4 to 30 cents per ton-mile, which is too wide a range and too few results for an accurate determination of the average cost of wagon transportation in Europe. In the third place, some of the results are professedly the cost to transportation companies, and some the cost to farmers to whom the hauling of the crops to market is merely an incident of farm work. And, finally, the data for the cost of hauling not done by transportation companies are for hauling garden products, etc., to large cities, and is therefore not representative of the cost of transporting general farm products to market. The cost of wagon transportation on the very best roads of Europe ought not to be very much less than the ordinary cost of hauling farm crops to market in America, for in most cases the latter is done when the roads are in fair or good conditions, and when in their best condition earth roads are nearly as good as the best stone roads.

26. It is very unfortunate that the conclusions from the two Circulars referred to above, have been so generally accepted by speakers and writers upon good-road economics. Country roads are used chiefly by farmers, and if improvements are made they must be paid for largely, if not entirely, by farmers; and therefore the cooperation of farmers must be secured before any improvement of the country roads is possible. Farmers instinctively know that conclusions such as deduced above from Table 2 are ridiculous, and not unnaturally distrust the motives prompting the argument, and are hostile to all propositions for road improvement supported by such arguments.

Further, it is not possible to determine either the cost of wagon transportation or the financial value of road improvement in the wholesale manner proposed in the above Circulars. The cost of

haul and the value of improved roads varies greatly with local conditions; and ordinarily it will be found that the probable saving in cost of wagon transportation alone is not sufficient to justify any radical road improvements. However, financial profit is only one of the advantages of good roads (see § 1–3).

27. TRACTIVE RESISTANCE. The resistance to traction of a vehicle on aroad consists of three independent elements: axle friction, rolling resistance, and grade resistance.

28. Axle Friction. The resistance of the hub to turning on the axle is the same as that of a journal revolving in its bearing, and has nothing to do with the condition of the road surface. The co-efficient of journal friction varies with the material of the journal and its bearing, and with the lubricant. It is nearly independent of the velocity, and according to observations made by the author seems to vary about inversely as the square root of the pressure. For light carriages when loaded, the co-efficient of friction is about 0.020 of the weight on the axle; for the heavier carriages when loaded, it is about 0.015; and for the ordinary thimble-skein American wagon when loaded, it is about 0.012. The above results are for good lubrication; if the lubrication is deficient, the axle friction is two to six times as much as above. The above figures agree reasonably well with results obtained for journal friction of machines. Apparently the value of this co-efficient in Morin's experiments (§ 34) was 0.065.* The greater axle friction is probably due to the inferior mechanical construction of French carriages and wagons.

The tractive power required to overcome the above axle friction for American carriages of the usual proportions is about 3 to 3½ lb. per ton of the weight on the axle; and for truck wagons, which have medium-sized wheels and axles, is about 3½ to 4½ lb. per ton.

29. Rolling Resistance. The resistance of a wheel to rolling along on a road is due to the yielding or indentation of the road, which causes the wheel to be continually climbing an inclination. The resistance is measured by the horizontal force necessary at the axle to lift the wheel over the obstacle or to roll it up the inclined surface; and varies with the diameter of the wheel, the width of the

* Lowe's Strassebaukunde, page 75. Wiesbaden, 1895.

tire, the speed, the presence or absence of springs on the vehicle, and the nature of the road surface.

30. *Diameter of Wheel.* The rolling resistance varies inversely as some function of the diameter of the wheel, since the larger the wheel the less the force required to lift it over the obstruction or to roll it up the inclination due to the indentation of the surface. Table 3 shows the results obtained by Mr. T. I. Mairs at the Missouri Agricultural Experiment Station,* with three different-sized wheels. The 50-inch represents 44-inch front wheels and 56-inch hind wheels; the 38-inch represents 36-inch front and 40-inch hind wheels; and the 26-inch represents 24-inch front and 28-inch hind wheels. The tires were 6 inches wide. The load was practically 1¾ tons in each case.

TABLE 3.

EFFECT OF SIZE OF WHEELS ON TRACTIVE RESISTANCE.*
Resistances in Pounds per Ton.

Ref. No.	Description of Road Surface.	Mean Diameter of Front and Rear Wheels.		
		50″.	38″.	26″.
1	Macadam: slightly worn, clean, fair condition.	57	61	70
2	Gravel road: dry, sand 1″ deep, some loose stones	84	90	110
3	Gravel road: up grade 2.2%, ½″ wet sand, frozen below	123	132	173
4	Earth road: dry and hard	69	75	79
5	" " ½″ sticky mud, frozen below, rough	101	119	139
6	Timothy and blue-grass sod: dry, grass cut...	132	145	179
7	" " " " wet and spongy.	173	203	281
8	Corn-field: flat culture, across rows, dry on top	178	201	265
9	Plowed ground: not harrowed, dry and cloddy	252	303	374
10	Average value of the tractive power	130	148	186

Morin concluded that the resistance varies inversely as the first power of the diameter of the wheel; Dupuit, that it varies as the square root; and Clarke claims that it varies as the cube root.† According to some experiments made in England in 1874,‡ the

* Missouri Agricultural Experiment Station, Bulletin No. 52. Columbia, 1902.

† Clarke's Construction of Roads and Streets, p. 294. London, 1890.

‡ Clarke's Manual of Rules, Tables and Data for Mechanical Engineers, p. 962. London, 1877.

tractive resistance varied more rapidly than the first power of the diameter of the wheels. The mean results in Table 3 vary nearly inversely as the square root of the mean diameter—certainly more nearly than as either the first power or the cube root. For obvious reasons, the experiments can not be very exact; and apparently the tractive resistance varies differently for different surfaces. The exact determination of the law of variation is of no great importance.

31. *Width of Tire.* If the wheel cuts into the road surface, the tractive resistance is thereby increased; but with surfaces for which there is little or no indentation, the traction is practically independent of the width of tire.

Table 4, page 24, shows the results of an elaborate series of experiments by the Missouri Agricultural Experiment Station.* The load in each case was 1 ton. These results show that on poor macadam, poor gravel, and compressible earth roads, and also on agricultural land, the broad tire gives less resistance except as follows: (1) when the earth road is sloppy, muddy, or sticky on top and firm underneath; (2) when the surface is covered with a very loose deep dust and is hard underneath; (3) when the mud is very deep and so sticky that it adheres to the wheel; or (4) when the road has been rutted with the narrow tire. The last conclusion was established by a large number of experiments not included in Table 4, page 24.

Table 5, page 25, gives data on the effect of width of tire upon the tractive power, obtained by the Studebaker Bros. Manufacturing Co., South Bend, Ind., in 1892, with an ordinary 3½-inch thimble-skein wagon. Notice that on a hard and incompressible road surface, e. g., wood block pavement and gravel, the narrower tire draws the easier; while upon the soft or spongy surface the wider tire draws the easier.

Morin experimented (see § 34) with tires 2½, 4½, and 6½ inches wide; and concluded that on a solid road or pavement the resistance was independent of the width of the tire, but on a compressible surface the resistance decreased as the width of the tire increased, the rate depending upon the nature of the surface.

* Missouri Agricultural Experiment Station, Bulletin No. 39. Columbia, Mo., July 1897.

TABLE 4.

TRACTIVE RESISTANCE OF BROAD AND NARROW TIRES.*

Resistances in Pounds per Ton.

Ref. No.	Description of the Road Surface.	Width of Tire.		No. of Trials.
		1½".	6".	
	Broken Stone Road:			
1	Hard, smooth, no dust, no loose stones, nearly level	121	98	2
	Gravel Road:			
2	Hard and smooth, few loose stones size of black walnuts	182	134	2
3	Hard, no ruts, large quantity of sand which prevented packing	239	157	1
4	New, gravel not compact, dry	330	260	1
5	Wet, loose sand 1" to 2½" deep	246	254	2
	Earth Roads:			
6	Loam,—dry, loose dust 2" to 3" deep	90	106	2
7	" " hard, no dust, no ruts, nearly level	149	109	3
8	" stiff mud, drying on top, spongy be low	497	307	1
9	" mud 2½" deep, very sticky, firm below	251	325	1
10	Clay,—sloppy mud 3" to 4" deep, hard below	286	406	1
11	" dry on top but spongy below, narrow tires cut in 6" to 8"	472	422	2
12	" dry on top but spongy below	618	464	5
13	" stiff deep mud	825	551	1
	Mowing Land:			
14	Timothy sod,—dry, firm, smooth, narrow tire cuts in 1"	317	229	1
15	" " moist, narrow tire cuts in 3½"	421	305	1
16	" " soft and spongy, grass and stubble 3" high, narrow tire cuts in 6"	569	327	1
	Pasture Land:			
17	Blue-grass sod,—dry, firm, smooth	218	156	2
18	" " soft, narrow tire cuts in 3"	420	273	2
19	" " narrow tire cuts in 4"	578	436	1
	Stubble Land:			
20	Corn stubble,—no weeds, nearly dry enough to plow	631	418	2
21	" " some weeds and stalks, dry enough to plow	423	362	1
22	" " in autumn, dry and firm	404	256	2
	Plowed Land:			
23	Freshly plowed, not harrowed, surface rough	510	283	1
24	" " harrowed, smooth, compact	466	323	1

* Missouri Agricultural Experiment Station, Bulletin No. 39, July 1897.

TABLE 5.

EFFECT OF WIDTH OF TIRE UPON TRACTIVE POWER.*

Resistances in Pounds per Ton.

Ref. No.	Description of the Road Surface.	Diameters of the Front and Rear Wheels Respectively.									
		3′ 6″ and 3′ 10″.		3′ 6″ and 3′ 10″.		3′ 8″ and 4′ 6″.		3′ 6″ and 3′ 10″.		3′ 8″ and 4′ 6″.	
		Width of the Tire.									
		1½″	4″	1½″	4″	1½″	4″	1½″	3″	1½″	3″
1	Sod	....	....	....	....	....	....	283	239	189	228
2	Earth Road, hard..	....	108	....	....	....	....	152	152	114	114
3	" " muddy	....	243	268	304	236	254	....	....	265	228
4	Sand Road, hard..	199	162	171	164	141	168	....	....	....	....
5	" " deep..	371	351	....	....	....	....	....	....	....	....
6	Gravel Road, good.	....	....	98	117	83	80	....	....	66	76
7	Wood Block, round	51	49	61	70	35	46	....	54	28	38

* Pamphlet by Studebaker Bros. Manufacturing Co., South Bend, Ind., 1892.

For a further discussion of the relative merits of broad and narrow tires, see § 188–90.

32. *Effect of Speed.* The rolling resistance increases with the velocity, owing to the effect of the shocks or concussions produced by the irregularities of the road surface. This increase is less for vehicles having springs than for those not having them, and is also less for smooth road surfaces than for rough ones.

Table 6, page 26, is a summary of Morin's results (see § 34) showing the effect of a variation of speed for vehicles provided with springs. In a rough way the three speeds are 2½, 5, and 7½ feet per second, or about 2, 4, and 6 miles per hour respectively. According to these results the resistance on broken-stone roads increases roughly as the fourth root of the speed, and on stone-block pavement about as the square root. For springless vehicles the increase would be greater. The above is for metal tires; for pneumatic tires there is very little increase of resistance with increase of speed.*

The preceding data refer to the effect of speed upon the tractive power after the load is in motion. It requires from two to six or eight times as much force to start a load as to keep it in motion at

* Proc. of Inst. of Mech. Engrs. (London), for 1890, Part No. 2, p. 105.

2 or 3 miles per hour. The extra force required to start a load is due in part to the fact that during the stop the wheel may settle into the road surface, in part to the fact that the axle friction at starting is greater than after motion has begun, and further in part to the fact that energy is consumed in accelerating the load.

33. *Effect of Springs.* Springs decrease the tractive resistance by decreasing the concussions due to irregularities of the road surface, and are therefore more effective at high speeds than at low ones, and on rough roads than on smooth ones. Apparently no experiments have been made upon the effect of springs; but a few data on this subject may be obtained by comparing the last and the sixth columns of Table 7, page 28.

TABLE 6.

EFFECT OF SPEED ON TRACTIVE POWER.*

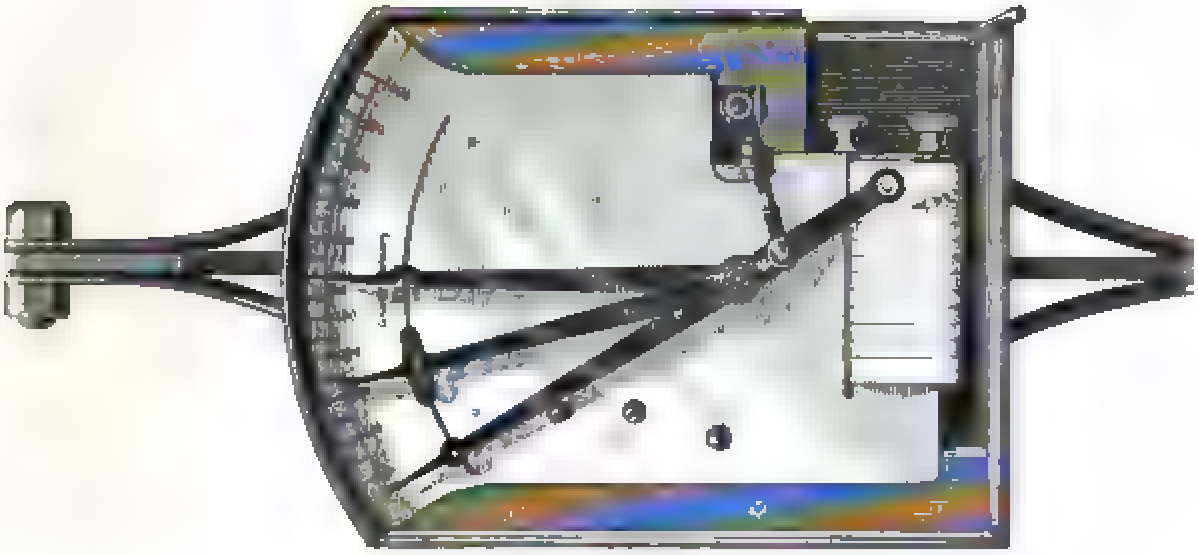
The figures give the resistance in pounds per ton.

Ref. No.	Description of the Road Surface.	Stage Coach.			Carriage.		
		Walk.	Trot.	Fast Trot.	Walk.	Trot.	Fast Trot.
	Broken Stone Road :						
1	Good condition, dry and compact	42	49	50	41	48	49
2	Very firm, large stones visible........	59	75	81	58	73	81
3	Little moist, or little dirty...........	49	75	88	48	74	88
4	Firm, little soft mud................	77	92	100	76	91	99
5	" ruts and much mud	95	108	117	93	108	116
6	Portions worn out, thick mud........	112	127	134	110	126	132
7	Much worn, ruts 3" deep, thick mud..	146	161	169	145	160	168
8	Very bad, ruts 4" deep, very rough...	164	180	....	162	202	....
	Stone Block Pavement :						
9	Very smooth, narrow joints..........	32	48	55	31	47	54
10	Fair condition, dry..................	35	52	61	34	51	67
11	Moist, covered with dirt.............	35	49	56	44	60	67

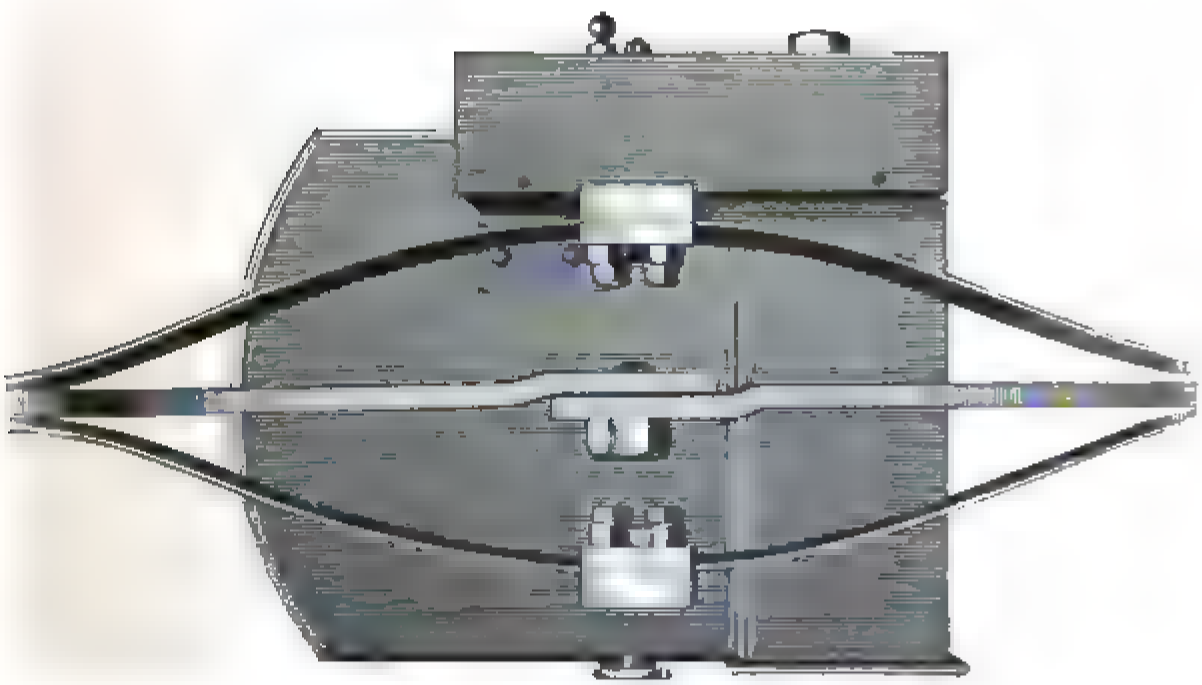
34. *Different Road Surfaces.* Immediately before and shortly after the introduction of railroads, European engineers made many experiments on the force necessary to draw different vehicles over various surfaces. The experiments by Morin,* made in 1837–41 for

* Expériences sur le tirage des voitures et sur les effets destructeurs qu'elles exercent sur les routes, executées en 1837 et 1838 par ordre du Ministre de la Guerre, et en 1839 et 1841 par ordre du Ministre des Travaux Publics, A. Morin. Paris, 1842.

the French Government, were much the most elaborate and appear to have been made with great care. Table 7, page 28, is a summary of Morin's results showing the tractive resistance for different vehicles



TOP VIEW



BOTTOM VIEW

FIG. 1.—BALDWIN DYNOGRAPH.

on various road surfaces. The table represents about 700 experiments. Any vertical column shows the resistance for a particular vehicle on the various road surfaces, and any horizontal line shows the resistance on a particular road surface for different vehicles.

TABLE 7.

TRACTIVE RESISTANCE OF DIFFERENT VEHICLES ON VARIOUS LEVEL ROADS, AT THREE MILES AN HOUR, IN POUNDS PER TON.

Ref. No.	Description of the Road Surface.	Vehicles with Springs.						Vehicles without Springs.		
		Gun Carriage. $t = 4.5''$ $a = 3''$ $D = 60''$	Freight Cart. $t = 4.5''$ $a = 2.5''$		Artillery Wagon. $t = 3''$ $a = 3''$ $d = 45''$ $D = 60''$	Freight Wagon. $t = 4.5''$ $a = 2.5''$		Stage Coach. $t = 4.5''$ $a = 2.5''$ $d = 36''$ $D = 56''$	Carriage. $t = 3''$ $a = 2''$ $d = 36''$ $D = 56''$	Wag'n. $t = 2.5''$ $a = 2''$ $d = 50''$ $D = 58''$
			$D = 64''$	$D = 80''$		$d = 36''$ $D = 60''$	$d = 44''$ $D = 78''$			
	Grass Plat:									
1	Very firm and dry	72	......	......	82	......	......	......	......	......
2	Moderately firm	87	......	......	100	......	......	......	......	......
3	A little moist	98	......	......	......	......	......	......	......	......
4	Slightly wet	140	......	......	160	......	......	......	......	......
5	Very wet, no water on surface	......	......	......	260	......	......	......	......	......
	Earth Road:									
6	Very good condition, nearly dry	57	55	44	66	74	63	77	76	64
7	Covered with untrodden snow	109	105	84	125	140	120	146	......	123
	Gravel Road:									
8	1¼" to 1½" loose gravel on firm earth	147	143	114	169	190	163	198	198	168
9	2" " 2½" " " " " "	172	168	134	198	225	192	233	233	198
10	4" " 6" " " " " "	185	180	144	216	241	206	250	250	212
11	4" " 6" " " and fine sand	196	190	153	247	251	217	267	290	225
	Broken Stone Road:									
12	Good condition, dry and compact	32	30	24	37	40	34	42	41	35
13	Very firm, large stones visible	37	35	28	43	47	40	49	48	41
14	Little moist or little dirty	45	43	34	52	57	49	59	58	50
15	Firm, little soft mud	57	55	44	66	74	63	77	76	64
16	" ruts and much mud	70	68	54	81	90	78	95	93	79
17	Portions worn out, thick mud	83	80	64	96	107	92	112	110	94
18	Much worn, ruts 3" deep, thick mud	109	105	84	126	140	120	146	145	123
19	Very bad, ruts 4" deep, very rough	121	118	94	140	157	134	164	168	139
	Stone Block Pavement:									
20	Very smooth, narrow joints	25	23	18	29	31	26	32	31	26
21	Fair condition, dry	27	25	20	31	34	29	35	34	29
22	Moist, covered with dirt	34	33	26	40	43	37	45	44	38
	Plank Road:									
23	Thick oak bridge floor	37	35	28	43	47	40	49	48	41

t = width of tire. a = diameter of axle. d = diameter of smaller wheel. D = diameter of larger wheel.

35. Table 8 shows data obtained by the author. The tractive power was determined with a Baldwin dynograph, Fig. 1, page 27. The instrument consists of two long flat springs fastened together at their ends and having their centers slightly farther apart than their ends. One end of the apparatus is attached to the wagon, and the team is hitched to the other. The pull of the team causes the centers of the flat springs to approach each other. One spring supports a graduated disk, and the other is connected to an index arm which is pivoted at the center of the disk. From one end of this index arm, the pull can be read directly from the graduated disk. There are two extra index arms—one to indicate the maxi-

TABLE 8.

TRACTIVE RESISTANCE ON LEVEL PAVEMENTS.

Ref. No.	Location and Description of the Pavement.	Pounds per Ton.
1	Asphalt. Chicago—Calumet Ave., bet. 43d and 44th Sts.; smooth, clean, no cracks, 52° F.	37
2	Chicago—Calumet Ave., bet. 43d and 44th Sts.; smooth, clean, no cracks, 84° F.	70
3	Chicago—Washington Boul., bet. Halsted and Green Sts.; smooth, clean, no cracks, 42° F.	34
4	Brick. Champaign—University Ave., west of New St.; 3 × 9-in. brick on concrete, corners rounded, sand filler, not worn, clean	17
5	Champaign—Second South St.; same as No. 4, except newer and covered with ¼ in. of dust	31
6	Champaign—First South St.: same as No. 4, except cement filler just completed	22
7	Chicago—Peoria St., between Washington and Randolph; 2½ × 8-in. brick on concrete, pitch filler, new	24
8	Chicago—Laurel St., Stock Yards; 3 × 8-in. brick on gravel and cinders, sand filler, corners not rounded	37
9	Chicago—Exchange Ave., Stock Yards; 2½ × 8-in. brick on sand and old macadam, tar filler, new	25
10	Granite block. Chicago—Exchange Ave., Stock Yards; smoothly dressed 3 × 9-in. blocks on concrete, joints ½ inch., tar filler, not worn	29
11	Chicago—Randolph St., between Desplaines and Halsted; smoothly dressed blocks on concrete, pitch filler, new	30
12	Chicago—Halsted St., between Randolph and Washington; ordinary granite, 9 years old	36
13	Macadam. Chicago—Michigan Ave., between 42d and 43d Sts.; granite top, no dust, no mud	18
14	Plank road: Chicago—Packer's Ave., Stock Yards; oak plank, 3 × 12-in., nearly new	32
15	Exactly same as above after worn down ½ inch in many places, clean	38
16	Substantially same as above: covered with ½ inch fine, loose dirt	40
17	Steel wheelway: Chicago—Transit Ave., Stock Yards; 8-in. 11½-lb. channel on 2 × 8-in. pine, that on macadam, covered with ½ inch powdered stone	40
18	Same when scraped with a shovel	19
19	Same when covered with ½ inch fine dust	28
20	Wood block: Rectangular blocks 3 × 12-in. considerably worn	36
21	Cylindrical cedar block, covered with ½ inch silicia pea gravel	90
22	Exactly same as above covered with ½ inch crushed gravel	50
23	Cylindrical cedar block, clean blocks slightly convex on top	53
24	Cylindrical cedar block on 2-inch plank and 2 inches of sand clean, not worn	37
25	Same as above: clean slightly worn	51
26	Same as above: clean considerably worn	54

mum power developed and one to indicate a rough average. The former (the upper one in Fig. 1) is simply pushed around by the main index arm and is left at the highest point. The latter (the middle arm in Fig. 1) has a transverse slot in which plays a stud on the main index arm. When making an experiment the main index arm is continually in motion, and the position of the auxiliary arm roughly indicates the average power exerted. The end of the index arm opposite the graduated arc records the amount of tractive resistance upon a strip of paper which is wound from one cylinder to another by clock-work located behind the lower right-hand corner of Fig. 1. The autographic record is more accurate than the indicated reading.

The wagon employed was the usual thimble-skein four-wheel farm wagon with a 2-inch tire. Experiments 3, 4, and 5 were made with wheels averaging 42½ inches in diameter, and the remainder with wheels averaging 47 inches.

36 From a study of the preceding experiments and also others not here described, it is concluded that the average tractive resistance on different road surfaces is about as in Table 9, page 31, which is given for use in comparing different roads and pavements.

37. Grade Resistance. This is the force required on a grade to keep the load from rolling down the slope. It is independent of the nature of the road surface, and depends only upon its angle of inclination.

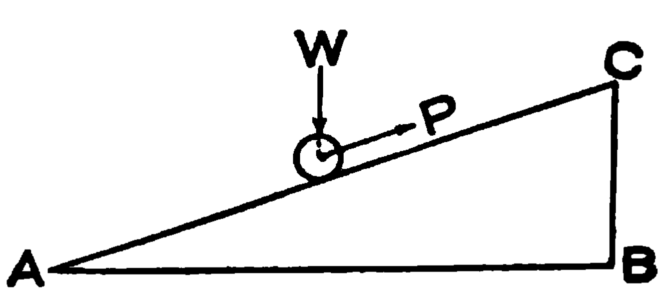


FIG. 2.

In Fig. 2, P is the grade resistance, and W is the weight of the wheel and its load. From the diagram it is easily seen that $P = W \times B\,C \div A\,C$. For all ordinary cases, $A\,C$ may be considered as equal to $A\,B$, and then $P = W \times B\,C \div A\,B$.

The preceding analysis is approximate for three reasons: (1) assuming $A\,C = A\,B$, i. e., assuming the sine of inclination to be equal to the tangent; (2) assuming the normal pressure on the inclined road surface to be equal to the weight, i. e., assuming the cosine of the inclination to be unity; and (3) neglecting the fact that the hind wheels carry a greater proportion of the load on an inclination than on the level. The resulting error, however, is wholly inappreciable.

TABLE 9.

STANDARD TRACTIVE RESISTANCE OF DIFFERENT ROADS AND PAVEMENTS.

Ref. No.	Kind of Road Surface.	Tractive Resistance.	
		Pounds per Ton.	In Terms of Load.
1	Asphalt—artificial sheet	30– 70	$\frac{1}{67}-\frac{1}{30}$
2	Brick	15– 40	$\frac{1}{133}-\frac{1}{50}$
3	Cobble stones	50–100	$\frac{1}{40}-\frac{1}{20}$
4	Earth roads—ordinary condition	50–200	$\frac{1}{40}-\frac{1}{10}$
5	Gravel roads	50–100	$\frac{1}{40}-\frac{1}{20}$
6	Macadam	20–100	$\frac{1}{100}-\frac{1}{20}$
7	Plank road	30– 50	$\frac{1}{67}-\frac{1}{40}$
8	Sand—ordinary condition	100–200	$\frac{1}{20}-\frac{1}{10}$
9	Stone block	30– 80	$\frac{1}{67}-\frac{1}{25}$
10	Steel wheelway	15– 40	$\frac{1}{133}-\frac{1}{50}$
11	Wood block—rectangular	30– 50	$\frac{1}{67}-\frac{1}{40}$
12	" " cylindrical	40– 80	$\frac{1}{50}-\frac{1}{25}$

Grades are ordinarily expressed in terms of the rise or fall in feet per hundred feet, or as a per cent of the horizontal distance. If *A B* be 100 feet, then the number of feet in *B C* is the per cent of the grade; and therefore the grade resistance is equal to the load multiplied by the per cent of the grade. Or the grade resistance is equal to 20 pounds per ton multiplied by the per cent of the grade.

38. POWER OF A HORSE. The horizontal pull which a horse can exert depends upon its weight, its form or build, the method of hitching, the foothold afforded by the surface, the speed, the length of duration of the effort, the rest-time between efforts, and the tax upon the future efficiency of the horse. The chief of these are the weight, the speed, and the length of the effort.

Horses vary in weight from 800 to 1,800 pounds. The larger horses do not usually travel more than 2½ or 3 miles per hour. With reasonably good footing a horse can exert a pull equal to one tenth of his weight at a speed of 2½ miles per hour (3⅔ feet per second) for 10 hours per day for 6 days per week and keep in condition. This is a common rate of exertion by farm horses in pulling plows, mowers, and other agricultural implements. On this basis a 1250-pound horse would develop 550 foot-pounds per second (the conventional horse-power), and 16,500,000 foot-pounds per day. A lighter horse will exert a proportionally less force. This may be considered about the limit of endurance. If the time of the effort

is decreased, the draft may be proportionally increased; or if the speed is increased, the draft must be decreased in a like proportion. In other words, the foot-pounds of energy that can be developed per day by any particular horse is practically constant.

The maximum draft for a horse is about half of his weight, although horses have been known to exert a pull of two thirds of their weight. Most horses can exert a tractive power equal to half their weight, at a slow walk for about 100 feet. On the road in emergencies, as in starting the load or in overcoming obstacles, a horse may be expected to exert a pull equal to half his weight, but at this rate he would develop a day's energy in about 2 hours; and consequently if he is expected to work all day, he should not be called upon to exert his maximum power except for a short time. Similarly, a horse can exert a draft equal to one quarter of his weight for a longer time. The working tractive power of a horse may be taken as one tenth of its weight, with an ordinary maximum of one quarter, and in great emergencies a maximum of one half its weight.

39. Increasing the number of horses does not increase the power proportionally—for somewhat obvious reasons. It is stated that for a two-horse team the efficiency of each horse is about 95 per cent; for a three-horse team, about 85 per cent. Of course such data are not much more than guesses.

40. Effect of Grade. The effective tractive power of a horse upon an inclined road surface is decreased by the fact that the horse must lift his own weight up the grade. If T = the tractive power on a level, W = the weight of the horse, t = the tractive power in per cent of the weight of the horse, and g = the per cent of the grade or inclination, then, with sufficient accuracy,

$$T = tW - g\,W = (t - g)W. \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

If it be assumed that the average working tractive power of the horse is one tenth of its weight, then $t = 10$, and equation (1) shows that on a 1 per cent grade the horse can exert an effective tractive power of 9 per cent of his weight, and also that he will be able to carry his own weight up a 10 per cent grade. If it be assumed that the horse exerts a tractive power equal to 20 per cent of his weight, then equation (1) shows that on a 10-per cent grade he can take his own weight up and in addition exert a tractive power of

10 per cent of his weight upon the load. By assigning values to t and g, equation (1) readily shows the effective draft of a horse upon any grade.

Equation (1) is not mathematically correct, since it assumes that the weight of the horse is always normal to the road surface. However, the formula is sufficiently accurate for use in comparing the relative tractive power of a horse on different grades (see § 41). At best such a formula can be only approximate, since the tractive power varies greatly with the foothold.

41. Maximum Load on a Grade. On a grade the effective tractive power as given by equation (1) is used up in moving the load over the road surface and in lifting the load vertically. If L = the load, and μ the co-efficient of road resistance, then

$$(t - g)W = \mu L + gL. \qquad (2)$$

and

$$L = \frac{t - g}{\mu + g} W. \qquad (3)$$

Equation (3) gives the load that a horse can draw up any road surface.

Table 10, page 34, is computed from equation (3) for a value of t equal to one tenth of the weight of the horse. The top line of the table shows the loads that a horse can draw on the level on the various road surfaces; and any column of the table shows the load that a horse can pull on any grade for that particular road surface.

As showing the different effects of grades upon different roads, notice that on a muddy earth road a 1 per cent grade reduces the load less than one tenth, while on asphalt a 1 per cent grade reduces the load more than one half; or, again, notice that with a 5 per cent grade, on iron rails the load is less than one twentieth of the load on the level, while on the best earth road the load is one fifth of that on the level.

Table 10 shows the load a horse can draw upon different grades and different road surfaces when exerting a uniform pull equal to one tenth of its weight. If we desire to know the maximum load which a horse can draw up any grade, we must insert in equation (3) the maximum value of t and compute the corresponding value of L. The value of t to be used in this computation will

TABLE 10.

Effect of Grade upon the Load a Horse can Draw on Different Roads.

The Load is in terms of the Weight of the Horse.

Ref. No.	Rate of Grade, per cent.	Iron Rails. $\mu=\frac{1}{200}$	Sheet Asphalt. $\mu=\frac{1}{100}$.	Broken Stone. $\mu=\frac{1}{60}$.	Stone Block. $\mu=\frac{1}{50}$.	Earth Road. Best. $\mu=\frac{1}{33}$.	Earth Road. Spongy. $\mu=\frac{1}{20}$.	Earth Road. Muddy. $\mu=\frac{1}{10}$.
1	0	20.00	10.00	6.00	5.00	3.00	2.00	1.00
2	1	6.00	4.50	3.33	3.00	2.09	1.50	0.91
3	2	3.20	2.67	2.16	2.00	1.51	1.14	0.67
4	3	2.00	1.75	1.49	1.40	1.11	0.87	0.54
5	4	1.33	1.20	1.05	1.00	0.82	0.66	0.43
6	5	0.91	0.83	0.75	0.71	0.60	0.50	0.33
7	6	0.62	0.57	0.52	0.50	0.43	0.36	0.25
8	7	0.40	0.38	0.34	0.33	0.29	0.25	0.18
9	8	0.24	0.22	0.21	0.20	0.18	0.15	0.11
10	9	0.15	0.10	0.09	0.09	0.08	0.07	0.05
11	10	0.00	0.00	0.00	0.00	0.00	0.00	0.00

TABLE 11.

Load which a Horse can Draw on a Grade in Terms of the Load on the Level when Exerting a Uniform Force Equal to One Tenth of its Weight.

Ref. No.	Rate of Grade, per cent.	Iron Rails. $\mu=\frac{1}{200}$.	Sheet Asphalt $\mu=\frac{1}{100}$.	Broken Stone. $\mu=\frac{1}{60}$.	Stone Blocks. $\mu=\frac{1}{50}$.	Earth Road. Best. $\mu=\frac{1}{33}$.	Earth Road. Spongy $\mu=\frac{1}{20}$.	Earth Road. Muddy. $\mu=\frac{1}{10}$.
1	0	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2	1	0.30	0.45	0.56	0.60	0.62	0.75	0.91
3	2	0.16	0.27	0.36	0.40	0.50	0.57	0.67
4	3	0.10	0.18	0.25	0.28	0.37	0.44	0.54
5	4	0.07	0.12	0.17	0.20	0.27	0.33	0.43
6	5	0.04	0.08	0.12	0.14	0.20	0.25	0.33
7	6	0.03	0.06	0.08	0.10	0.14	0.18	0.25
8	7	0.02	0.04	0.06	0.06	0.10	0.12	0.18
9	8	0.01	0.02	0.04	0.04	0.06	0.08	0.11
10	9	0.01	0.01	0.02	0.02	0.03	0.04	0.05
11	10	0.00	0.00	0.00	0.00	0.00	0.00	0.00

depend upon the length of the grade and upon the frequency with which it occurs. If the grade is only a few hundred feet long, it will probably be safe to assume a pull equal to one fourth of the weight of the horse; but this value should be assumed only for the

maximum grade, since such pulling is too exhausting for continuous work.

Table 11, page 34, presents the same data as Table 10, but in a slightly different form.

42. The maximum load which a horse can draw upon any road, particularly upon the steepest grade, is not, however, necessarily proportional to the rate of grade and to the resistance, since the pull that a horse can exert depends upon the foothold. Owing to the danger of slipping on steep grades, particularly when the road is wet or icy, it is not customary to lay sheet asphalt on grades of more than 4 per cent, or ordinary stone blocks on more than 10 per cent. On steeper grades, special forms of stone blocks are sometimes employed to increase the tractive power by affording better foothold for the horses.

43. ROAD ADMINISTRATION. Up to the present time, with but few exceptions, the management of roads has rested upon local authorities, either those of townships or counties. In those cases in which the administration of road affairs is nominally in the hands of the county authorities, nothing has usually been done except to divide the county into road districts and virtually transfer all authority to local officials appointed for that purpose. Apparently it is impossible to secure either good roads or an efficient road administration by the action of officials who have only local authority, and who are necessarily swayed by purely local, if not individual, interests. This is not peculiar to America, since great difficulties have always been encountered in maintaining a system of public highways by any locally governed community.

The fundamental difficulty is that the small administrative unit makes it impossible to secure efficient supervision, since the time necessarily required in road administration is but an incident among private or official duties. Another difficulty is that the official is usually elected for political reasons, rather than for his ability in matters relating to the roads. A further difficulty is that the tenure of office is short, and successive officials have conflicting views as to road administration and road improvement.

Another objection to the small administrative unit is the improbability of the district's having suitable machinery in sufficient quantity to effectively and economically care for the roads. At

present a large amount of time is wasted in transferring machinery from one locality to another.

44. Classification of Roads. As a remedy for present evils, it has frequently been urged that the roads should be classified, according to their importance, into state, county, and township roads, or into county, township and neighborhood roads, the roads of each class to be under a corresponding administrative board. The possibilities and need of this classification vary greatly with the topography of a locality. For example, in a prairie country one road is nearly as good as another, the market places on the railroads are nearly uniformly distributed, and all of the roads have substantially equal traffic; while in a broken country the railroads are in the valleys, and a wagon road in a valley may carry the traffic for a very large outlying area. The proposed classification has never been practically tried in this country except perhaps in the cases where state aid is granted—as will be considered presently (see § 54). The proposed change promises some advantages, but it is by no means proved that the difficulties of administration would be lessened or that the quality of the roads would be improved.

In some of the older countries of Europe, the public highways are classified in a manner similar to that referred to above, and the work of administration seems to be reasonably effective; but success in Europe does not guarantee equal success in America with its different social, political, and industrial conditions.* There is also an important difference between our own and European countries as to the abundance and distribution of road-building material (§ 300), and also as to the length of roads proportional to area and population.†

To a great extent, the nations of Europe which are noted for their improved highways were experienced in road building and administration before the advent of railroads; and consequently a large proportion of the wagon roads are permanently hard roads—either broken stone or stone block. On the other hand, the development of America has taken place to a large degree since the intro-

* For an outline of the systems of road administration in the several American states and in the countries of Europe, see page 14–37 of Annual Report of the Department of Highways of the State of California for 1900.

† See an article by the author in Proc. Ill. Soc. of Engineers for 1902, p. 144–48.

duction of railroads, the railroad in many cases preceding the coming of the population; and consequently the railroad has made unnecessary national or state wagon roads. A large proportion of the wagon roads of America are purely local, i. e., run from the farm to the railroad town, and only those near the large cities have more than local importance; and hence a large proportion of American roads have only an earth surface, and do not require as close watching nor as much care as the more expensive European roads with their greater traffic. Ordinarily, in America the amount of money expended per mile of road is so small that any adequate supervision by a county or state official would probably add disproportionately to the expense (see § 51).

Although in America there are no roads of state or national importance as lines of communication, yet as factors in the general welfare of the people wagon roads are of general interest and concern to both the state and the nation.

45. Education vs. Legislation. Unquestionably the prevailing American system is not perfect, but a practical solution of the problem—one that will meet all the conditions—will be found difficult of attainment. It is easy to criticise existing evils, to point out unerringly the incongruities of the diversified provisions of the statute books relative to roads, and to join in a general demand for reform. Apparently the greatest hope for an improvement in the public roads and in road administration, is in calling attention to the defects in the present methods and in offering suggestions for their improvement. It is better to try to grow into an improved system of road management by adopting first that which is most essential or the easiest to obtain—then taking other steps as the people become educated to the importance of efficient road administration,—rather than to attempt a revolution in road affairs by legislation. Our efficient railways were not created in a day, but are a natural development. A cheap line was first constructed, and this was gradually perfected as the necessary money could be obtained and as the conditions were better understood and as the requisite skill was developed.

It is probably wiser to direct attention to the defects in the present roads and to the inefficient administration of the present laws, than to attempt to secure improved roads and effective admin-

istration by enacting new laws. As illustrating the improbability of securing improved road administration by legal enactment unsupported by public sentiment, it may be mentioned that in Illinois a state law wisely requires that the major part of the labor road-tax shall be paid in May and June,—when the roads most need attention and when the labor would be most effective;—but the law is practically a dead letter, since in those months the farmers are more interested in putting in their crops.

For a valuable discussion of European and American systems of road administration, see pages 88–108 and 176–185 of Shaler's American Highways, New York, 1896.

46. The following extracts from a farmer's bulletin by the author, suggests some details as to the methods to be employed in securing an effective administration of road affairs. These suggestions were made with direct reference to earth roads—which constitute perhaps 90 or 95 per cent of the highways of this country, —but they are hardly less applicable to any system of roads.

"1. It is believed that material improvement can be attained by paying more attention to the office of Highway Commissioner and Pathmaster. Elect only the very best men, without regard to party; men who have judgment in business affairs, who have ideas on road making and maintenance, who have skill in directing the labor of others, and who will give to their official duties their best endeavor. If they do reasonably well and are continually seeking to increase their road knowledge and to improve the roads under their care, continue them in office. If not, try again to find some one who will do these things. Dignify the office by every means possible.

"2. In private conversation and in public meeting, discuss ways and means of improving the earth roads. Organize for the purpose of creating interest in common earth roads. As soon as possible adopt rules for the guidance of the road officials, and then let each tax payer note whether these rules are obeyed. Do not fail to give due credit if they are; and if they are not, do not shrink from entering a respectful protest. Unless the earth roads are maintained in reasonably good condition, it is folly even to talk of constructing high-priced broken-stone roads.

"3. Divide the roads up and allot definite sections to particular

farmers, and publish these allotments, which fixes responsibility. As far as possible require each man to care for the road nearest home and which he travels most. By private conversation and public meeting seek to stimulate pride in road making and maintenance, and try to secure the effect of competition in road work. Possibly have annual inspections, and award prizes and diplomas. Railroads find annual inspections and nominal cash prizes and diplomas exceedingly effective. France has a system of gratuities for excellence in road work.

"4. Permanently hard roads are very desirable if their cost is not too great; but remember that high-class stone or gravel roads are not feasible unless the road-bed is thoroughly underdrained, and unless the subgrade is adequately crowned, and unless the public understands the superiority of perpetual maintenance over annual repairs, and unless the road officials are intelligent, energetic, and conscientious. Fortunately these things are the very best investments for earth roads, and good earth roads are the very best preparation for good gravel or broken-stone roads.

"5. Do not overlook the fact that the interest in good roads should have a broader foundation than mere commercial needs. Comfortable and easy communication between the members of a rural community and also between rural and urban inhabitants is of great importance in the social and educational development of a community."

47. ROAD TAXES. How shall the expense of constructing and maintaining roads be distributed? This question has been answered in various ways in different parts of this country and in different countries of Europe. There are three forms of road taxes; viz.: (1) a tax upon the traveler, (2) a capitation tax, and (3) a property tax. The first leads to toll roads; and the second is usually called a poll-tax.

48. Toll Roads. These are conducted on the theory that the travelers over a road are the recipients of its benefits and should pay for its support. Toll roads are justifiable only in a new country where the amount of taxable property is small, and where for long stretches of territority there are few inhabitants, since they induce the investment of capital that possibly the pioneer or the new community could not afford; and even under these conditions they

are practicable only where there is considerable traffic. In early times the government collected the toll and used it for the maintaining and extension of the road; but in recent times toll roads are usually in the hands of private capitalists.

Toll roads are objectionable owing to the proportionally great expense of collecting the revenue, and owing to the fact that they are managed solely with reference to securing returns upon the capital invested and without regard to the interests of the public. The only remedy for the evils of the system is for the public to support the roads. Roads are an indispensable public convenience —a benefit to every citizen, whether a direct user of the road or not,—and consequently should be maintained by a universal tax. At present the toll system is regarded as unwise for both economic and political reasons; and toll roads have almost entirely been abolished both in this country and in Europe.

49. Poll-tax. Notwithstanding the fact that most writers on political economy consider a capitation tax an undesirable form of taxation, nearly all of the states levy a poll-tax for road purposes. Apparently it is the only capitation tax. It is not wise to occupy space here to inquire into either the wisdom or reason for this form of road taxes.

Almost universally the law permits the payment of the poll road-tax in money or labor, and it is usually paid in labor. In the poorer and less populous states, this tax is nearly the sole support of the road system. In many states there are numerous exemptions, and in all states the tax is difficult to collect, and consequently the poll-tax is an unimportant element in road construction and maintenance.

50. Property Tax. There are three forms of the property road tax: the special assessment, the direct tax, and the general tax.

In many states when any considerable road improvement is contemplated, part or all of the cost of the same is laid as a special tax or assessment on all real estate within some certain distance of the improvement. In Indiana at one time, this distance was two miles; and in Wisconsin, three. Ordinarily this tax is not uniform over the included area, but is graded according to the supposed benefits. This tax is usually payable in money.

In most of the states, the territory is divided into small units,

called road districts, and a uniform road tax is laid upon all property within the district. Usually this tax may be paid in either money or labor; and when so permitted, is usually paid in labor.

In most states there is also a general property tax for road and bridge purposes, which must be paid in money.

In poorer communities the roads are cared for principally by the district road tax, which is usually paid in labor; but in wealthier communities the general property road and bridge tax (cash tax) is greater than the district road tax (labor tax).

51. Cost of Roads. There are almost no definite data as to the amount expended for road purposes. The following are all that can be found.

In Massachusetts the average of the annual expenditures of the towns (townships), exclusive of the cities, for highways, exclusive of the bridges, for the years 1889, 1890, 1891, were as follows: * $22.17 per mile of road, the range for the different towns (townships) being from $2.20 to $191.00; $50.72 per square mile; or $0.46 per capita, the range being $0.06 to $4.68. In 20 per cent of the townships, the average annual expenditure was $5.40 per mile; in the next 27 per cent, $9.60; and in the next 18 per cent, $12.73. These were the expenditures before the inauguration of state aid (§ 54). It is interesting to note that the per cent of the total tax-receipts spent upon the roads is practically the same in the rural districts as in the cities, being 13.7 per cent in the former and 11.2 in the latter.

"In 1893 the road expenditures in New Jersey were $778,470.82, or $43.24 per mile (about one fifth being for new broken-stone roads); in New York about $2,500,000, or about $30 per mile."†

In Vermont in 1893 the expenditures for road purposes, including culverts but excluding bridges, in country and cities, were $30.22 per mile; and in 1894, $32.13.‡

In Connecticut in 1889 the expenditures for roads in the different townships averaged $34.04 per mile, the maximum being $201.22 and the minimum $7.91.§

* Report of Massachusetts Highway Commission for 1893, p. 218–31.

† Gen. Francis V. Greene, before the students of Union College, Schenectady, N. Y., reprinted in Bulletin No. 17 of the Road Inquiry Office of the U. S. Department of Agriculture.

‡ Report of Highway Commission, 1894, p. 77–91; 1896, p. 61–74.

§ Proc. Conn. Assoc. of Civil Engineers and Surveyors, 1890 and 1891, p. 107–110.

"The public roads of Washington County, Md., have cost $20 per year." *

In Champaign county, Ill., according to statistics collected by the author,† the expenditures for road purposes, outside of incorporated cities and villages, in 1900 were $34.86 (for details see § 220).

52. Labor vs. Money Tax. In all the states except five, the labor tax is regularly employed.‡ In one state at least (Illinois) the road tax may be collected in money or labor as the township by election may decide,—and a large majority of the towns vote in favor of the labor system. The labor-tax system was inherited from England, and is a survival of the feudal method of requiring all able-bodied men to render public service. England and France have a labor road-tax, but upon a much less extensive scale than has this country.

The roads and streets of the cities, towns, and villages are usually under the control of the municipalities, in which as a rule the labor tax does not exist; therefore the labor-tax system applies chiefly, if not wholly, to rural communities. Further, since a very large proportion of the roads are of earth, the labor-tax system is usually applied to the construction and care of earth roads.

It is common to assume that the labor-tax system is all wrong, and that its evils would be escaped by paying road taxes in money. The labor tax has inherent disadvantages, but many of the defects charged to it belong rather to defective administration and to the system that leaves the control of the public highways to a small locally governed community. Public work is seldom as economically done as private work.

The objections to the labor-tax system are: 1. The labor is indifferent and inefficient. 2. It is impossible to get the work done at the most suitable time. 3. The system allows no selection of the laborer. All of these are important considerations.

The reply to the above objections is usually about as follows: 1. The farmer is willing to pay more in labor than in money, which compensates in part, at least, for the objections to the labor-tax system. This preference is not peculiar to the American farmer.

* Trans. Amer. Soc. of C. E., Vol. 28, p. 111.

† Proc. Illinois Society of Engineers and Surveyors, 1901, p. 48–52.

‡ Road Legislation for the American State, Jeremiah W. Jenks, Baltimore, 1889.

In France, if the road tax is paid in money, a reduction of 40 to 50 per cent is made; but still 60 per cent of the people prefer to pay in labor.* Farmers not infrequently give more both in labor and money than is exacted as road taxes, because they are interested in better roads. 2. In many rural communities it is impossible to secure any one to do road work at reasonable wages at the most suitable season. 3. If the tax were paid in money, there is no certainty that the labor would be any more efficient. Streets are maintained under the cash-tax system, but the labor is not ideally efficient. The authority that virtually wastes the labor tax will probably also waste the cash tax.

53. The labor tax is not necessarily the cause of inferior roads, nor the cash-tax system in itself the cause of improved roads. Townships under the labor-tax system often have better roads than adjoining townships under the cash-tax system. The one thing absolutely necessary for successful road management is effective supervision of the work. Without it neither system will accomplish much, and with it either system will do reasonably well.

Many townships have changed from the labor-tax system to the cash-tax system with a marked improvement in the condition of the roads—due chiefly, if not wholly, to better administration. For in many of these cases the so-called cash-tax system is practically only a change in the method of administering the labor-tax system, since farmers desiring to do so are given an opportunity to work out their road taxes under the cash system. Under the labor-tax system those working upon the roads receive credit on their road taxes, while in the so-called cash system the laborer receives an order which is accepted as cash in paying taxes. In these cases the public sentiment that demanded road improvement secured the change from the labor tax to the cash tax; and, consciously or unconsciously, also secured a more efficient road administration.

The labor-tax system is more objectionable with broken-stone roads than with earth ones, since the construction of the former is more difficult and their maintenance requires intimate knowledge and constant attendance, and also since the former are built only where there is more travel and where the labor of maintenance is

*French Roads, their Administration, Construction, and Maintenance, Prof. Frank H. Neff, Jour. Associated Eng'g Societies, Vol. 11, p. 1–16.

greater. This subject will be considered incidentally under Maintenance in the chapters on earth, gravel, and broken-stone roads.

54. State Aid. In 1891 New Jersey inaugurated a new departure in road administration in America—that of state aid in road construction. A state law provides that on the petition of a majority of the adjacent property owners, a gravel or broken-stone road shall be built, under the direction of the State Highway Commissioner, 33⅓ per cent of the expense to be borne by the state, 10 per cent by the abutting property, and 56⅔ per cent by the county. The maintenance of the improved road is in the hands of the county officials.

In 1893 Massachusetts inaugurated a somewhat similar system of state aid for road improvement. Under the Massachusetts law the road improvement may be petitioned for by the town, county, or city authorities; and the state bears 75 per cent of the expense, and the county 25 per cent. Notice that no part of the expense of the improvement is laid directly upon either the abutting property or the township. This is a concession to the poorer communities, which are frequently most in need of improved highways. The maintenance of the roads is in the hands of the township authorities, with a general oversight by the State Commission.

In 1895 Connecticut inaugurated a similar system of state aid. The distribution of the expense has changed from time to time: in 1895 one third each by state, county, and town; in 1897, one half each by state and town; and in 1899, one third by small towns and two thirds by large towns, the remainder in each case by the state.

In 1898 New York adopted a state-aid system, whereby the state pays 50 per cent, the county 35 per cent, and the town 15 per cent. The practice in New York differs from that in the other states in that the state-aid fund may be used for the improvement of earth roads.

55. The principle of state aid is defended on the ground that (1) it secures centralized control, (2) makes the wealth of the city bear part of the expense of maintaining the country roads, and (3) compels the railroads and other state-wide corporations to bear part of the expense of local improvements.

In Europe nearly all countries give national aid in some form for building roads.

CHAPTER II.

ROAD LOCATION.

56. ELEMENTS INVOLVED. In general the determination of the best location for a road requires a study of the topographical features of the region through which the road is to pass, and also an investigation of the nature and extent of the traffic to be provided for. Viewed as a question of economics, the best location is that for which the sum of the interest on the cost of construction and of the annual cost of maintaining the road and of conducting transportation over it, is a minimum. The location of a wagon road is not, however, entirely a question of economics, since the location should be made with reference to the convenience and comfort, and perhaps also to the pleasure, of those who use it; and is frequently more of a social or political question than one of economics. Only the economic features of location will be considered here, and they only briefly.

However, in locating a new wagon road, it is well to remember that the location will probably serve for many generations, and perhaps for all time, as the growing importance of the surrounding country and the location of buildings and of division lines of the land with reference to the road make it increasingly more difficult and expensive to change the location. Thus the location of a road is the field where costly errors and permanent blunders may creep in and forever fasten themselves upon the road and its users; and, worst of all, these errors become more costly as the use of the road increases.

In most parts of the United States, the roads are in the main already located, and the necessity for the location of new ones does not often arise; and hence as a rule, the only application of the principles of economic location will be in the re-location of comparatively short stretches of roads. The original location may

have been fit and proper when the region was new and undeveloped, but the increase in the amount and the change in the character of the traffic may justify a very considerable change. There are many roads that could be materially improved by a careful re-location.

57. The principles to be observed and the methods to be employed in making the location of a wagon road are substantially the same as those used in the location of a railroad. The method of examining the country and of making surveys will not be considered here, as such subjects are elaborately presented in treatises on railroad location.

The fundamental principles applicable in locating a new road or in improving an old one will be briefly considered; but no hard and fast rules can be laid down, for each road must be designed for the place it is to occupy and the service it is to render. In the location of any road there will always be an opportunity to exercise keen insight and good judgment.

The subject will be considered under the four heads: distance, grades, curves, width, and placing the line.

58. DISTANCE. Other things being equal, the shorter the road the better, since any unnecessary length causes a constant threefold waste: (1) the interest on the cost of constructing the extra length; (2) the ever-recurring cost of repairing it; and (3) the time and labor employed in traveling over it. However, the advantage of straightness, i. e., of shortness, is usually greatly overestimated. The difference in length between an absolutely straight line and one deflecting a little to one side is not very great. For example, in Fig. 3, if $A\,B = B\,C = 1{,}000$ feet, and $B\,D = 10$ feet, the line $A\,B\,C$ is only one tenth of a foot longer than the line $A\,D\,C$.* If $A\,B = B\,C = 1$ mile, and $B\,D = 300$ feet, the line $A\,B\,C$ is only 17 feet longer than $A\,D\,C$. "If a road between two places ten miles apart were made to curve so that the eye could nowhere see more than a quarter of a mile of it at once,

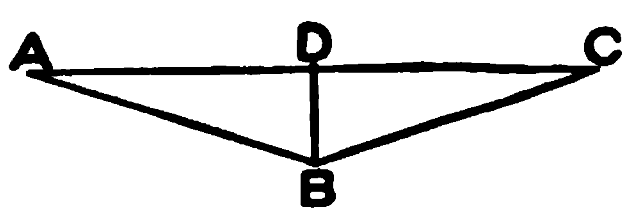


FIG. 3.

* The difference between $A\,D$ and $A\,B$ is given with sufficient accuracy by the approximate formula: $A\,B - A\,D = \frac{D\,B^2}{2\,A\,D} = \frac{D\,B^2}{2\,A\,B}$. For the demonstration of this formula, see the author's Engineer's Surveying Instruments, p. 16.

its length would exceed that of a perfectly straight road between the same points by only about one hundred and fifty yards." *

One of the most common defects of ordinary country roads is that distance has been saved by a disregard of the desirability of easy gradients. The curving road around a hill may often be no longer than the straight one over it; for the latter is straight only with reference to the horizontal plane, but curved as to the vertical plane, while the former is curved as to the horizontal plane, but straight as to the vertical plane. Both lines curve, and the one passing over the hill is called straight only because its vertical curvature is less apparent to the eye.

59. Value of Saving Distance. Theoretically the value of a difference in length may be computed by determining (1) the amount of traffic, (2) the cost per ton-mile, and (3) the total cost of conducting the traffic; and then assuming that the value of any difference of length is to the total cost of transportation as the difference of the length is to the total length. If the annual cost of conducting transportation over a given road is known, then this cost divided by the length of the road gives the annual interest upon the sum that may be reasonably expended in shortening the road 1 mile, i. e., the value of a saving of a mile of distance; and of course dividing this sum by the number of feet in a mile will give the value of saving 1 foot of distance.

Unfortunately it is not possible to determine the amount of traffic with any considerable degree of accuracy. At some railroad stations the sole freight shipped out is agricultural produce, in which case the traffic over any particular wagon road can be approximated by distributing the shipments according to the contributing area. The average load can be determined with sufficient accuracy by consulting the records of the grain dealers. In addition to the above, which may be called the heavy freight traffic, there is a considerable amount of light freight and passenger traffic which would be benefited by a saving of distance.

For the sake of working out an example, it will be assumed that the cost of transportation is 10 cents per ton-mile. This cost is made up of the cost of loading and unloading, of driving, of feed,

* Gillespie's Manual of Road Making, p. 27. New York, 1847.

and of wear and tear of horses, wagon, and harness. The cost of loading and unloading is independent of distance. The cost of driving nominally varies as the time, i. e., as the distance (see third paragraph of § 60). The cost of feed and of wear and tear varies as the distance. It is impossible to assign reliable values to these several factors of the cost, but it is certain that only part of the cost of transportation varies as the distance; and for the sake of completing the illustration, it will be assumed that 8 cents per ton-mile varies as the distance. This sum multiplied by the number of tons passing over the road in a year will give the sum that may be spent annually to secure a saving of 1 mile of distance.

For example, a road leading to a certain village was originally laid out on the east and north sides of a quarter-section, but on account of low ground on the northeast corner another road was opened on the south and west sides. The quarter-section was one large field. How much expense would the traffic justify in order to secure a road diagonally through the quarter-section? The heavy freight traffic was approximately 3,000 loads of 1 ton each per annum. The annual value of saving 1 mile would then be 8 cents$\times$3,000= \$240. The saving in distance by going through the quarter-section is 0.29 mile; and the annual value of saving this distance is \$240$\times$0.29=\$69.60. The diagonal road occupies $2\frac{1}{3}$ acres less land than the longer one; and as the land rented for \$3 per acre, this adds \$3$\times 2\frac{1}{3}$=\$7 per annum to the value of the diagonal road. The annual saving from these two items is then \$69.60+\$7.00=\$76.60. This is the interest at 5 per cent on \$1,532, which sum, according to the above computations, could be borrowed, and used to secure this improvement, and the community be no worse off financially.

In addition, there would be some advantage to the light freight and passenger traffic by shortening the road, but it is difficult, if not impossible, to estimate this saving; and as the benefit per trip would probably be less than for the heavy freight traffic, it was neglected. There would be a slight saving in the cost of maintenance of the shorter road, as in this case the soil and drainage was as good on one line as on the other. Further, there would be some saving on the return trip by the shorter road. On the other hand, it is probable that the smaller number of acres required for the diagonal road would cost at least as much as for the road around

the quarter-section, owing to the farmers' justifiable dislike for non-rectangular fields, and because the diagonal road would divide the quarter-section.

60. There are several matters that materially affect the reliability of the method of the above investigation. In the first place, the cost of transportation can not be known with any degree of reliability. The farmers concerned would stoutly contend that the price assumed above is much too great (see § 20–21); while freighters would claim that the value assumed was too low (see § 4–7).

In the second place, not all of the computed annual saving is available for making the improvement, since some of it should be set aside to form a sinking fund to be used ultimately in extinguishing the debt. It is not the part of wisdom to extend the debt very far into the future, since the conditions may materially change. For example, a new railroad may divert the traffic from this particular road, or improvements in the condition of the surface of the road may decrease the cost of transportation,—either of which would decrease the value of the proposed improvement. Of course, certain contingencies may increase the traffic and thereby add to the value of the improvement; but it is not wise to incur a definite debt for an equal and somewhat problematic saving. Road reformers sometimes overlook the fact that interest is a yearly charge and that the debt must finally be paid.

In the third place, the cost of transportation does not necessarily vary proportionally to the distance, as was assumed above. If the difference in distance is sufficient to make a difference of one trip per day, then the value of the saving in distance is tangible; but where the saving in length is insufficient for an additional trip, the value of the difference in distance depends upon the value, for other work, of the small portions of time of men and teams which may be saved by the shorter route,—a value which exists, but which is difficult to estimate.

Therefore any estimate as to the value of a saving of distance is necessarily only a rough approximation; and at best it should be used only as a guide to the judgment.

61. The problem to find the value of saving distance is very different for wagon roads than for railroads. In the case of railroads the cost of the various elements has been carefully investigated for

many years, and the transportation is all conducted under a single management and by the same party that maintains the road surface; while in the case of wagon roads, a multitude of private parties conduct the transportation under various conditions, and the maintenance of the road is in the hands of public officials.

62. GRADES. A level road is the most desirable; but as it can seldom be obtained, we must investigate the effect of grades upon the cost of constructing and operating the road, and also determine what is the steepest allowable grade.

The grade may be reduced (1) by going round the hill or by zigzagging up the slope, or (2) by cutting down the hill. If the slope to be ascended is a long one, the first method must be employed; but if the grade is short, the second is usually the cheaper. Increasing the length adds to the cost of construction and of transportation, while cutting down the hill adds only to the cost of construction. The maintenance of the longer and flatter line may cost either more or less than the shorter and steeper one according to the circumstances of the case. In a broken or rough country, a proper adjustment of the grades is the most important part of the art and science of road building; and the better the road surface the more necessary is such an adjustment.

63. All grades are objectionable for two distinct reasons, viz.: because a grade increases the amount of power required to move a load up it, and because a grade may be so steep as to limit the amount of the load that can be moved over the road. The first applies to all grades whatever their rate or height; while the latter applies only to the steepest grade on the road, and in a measure is independent of its height and depends only on its rate. At present only the first objection to grades will be considered; and subsequently the second objection will be discussed (see § 71).

64. Effect of Grade upon Load Table 10, page 34, shows the load (in terms of the weight of the horse) which a horse with a pull equal to one tenth of his weight can draw up various grades on several road surfaces. To emphasize the effect of the grade upon the load, the same data are presented in a slightly different form in Table 11, page 34, which shows at a glance the load on any grade in terms of the load on the level. Tables 10 and 11 show that the better the condition of the road surface, i. e., the less the rolling

resistance, the more deleterious a grade. For example, according to Table 11, on iron rails on a 3 per cent grade a horse can draw only 10 per cent as much as on a level; while on a broken-stone road on a 3 per cent grade he can draw 25 per cent as much as on a level.

A horse can occasionally and for a short time exert a pull equal to more than one tenth of his weight. If the grade is not too long, a horse can safely exert a force equal to one quarter of his weight, and in emergencies one half. If the maximum force exerted is equal to one quarter of his weight, up what grade can he pull the ordinary load?

To move a load over an ordinary earth road requires a tractive force of 100 lb. per ton (see Table 9, page 31), and therefore a team of 1200-pound horses exerting a force equal to one tenth of their weight can draw 2.4 tons on the level. The reserve power to take the load up the hill is $(0.25-0.10)\times 1200\times 2=360$ pounds. The total load to be carried up the grade is the wagon and its load *plus* the weight of the team, or $2.4+(1200\times 2\div 2000)=3.6$ tons. The grade resistance is 20 lb. per ton for each per cent of inclination (see § 37); and the grade resistance for this load on a 1 per cent grade is $3.6 \times 20 = 72$ lb. Therefore, the grade up which a pull of 360 lb. will take the 3.6 tons is $360 \div 72 = 5$ per cent, which is the maximum permissible grade for an earth road in ordinary condition. The team could probably pull this load up 400 to 500 feet of such a grade.

By the same method of analysis, the load for the same team on a level, muddy earth road having a tractive resistance of 200 lb. per ton is 1.2 tons, and the maximum permissible grade is 7.5 per cent.

For a broken-stone road having a tractive resistance of 33 lb. per ton, the load on the level is 7.3 tons, and the permissible maximum grade is 2.2 per cent.

65. What load can the above team take up a 4 per cent maximum grade on a broken-stone road having a tractive resistance of 33 lb. per ton? The grade resistance is $20 \times 4 = 80$ lb. per ton; and the tractive resistance is 33 lb. per ton; therefore the total resistance is $80 + 33 = 113$ lb. per ton. The maximum tractive power of the team is equal to one quarter of its weight, or 600 lb.; and the grade resistance for the weight of the team $= 2400 \div 2000 \times$

80=96 lb.; therefore the net tractive power of the team is 600−96=504 lb. Then the weight of the wagon and the load which the team can draw up this grade is 504 ÷ 113 = 4.4 tons.

The above computations are for two 1200-pound horses, but the conclusions would not materially differ for horses of other weight.

66. Rise and Fall. By rise and fall is meant the vertical height through which the load must be lifted in passing over the road in each direction. One foot of rise and fall is a foot of ascent with its corresponding foot of descent. In passing over a ridge 10 feet high standing in the middle of a level plain, there is only 10 feet of rise and fall; and not 10 feet of rise plus 10 feet of fall. If the road is level, Fig. 4, then an elevation or depression of, say, 1 foot produces literally 1 foot of rise and a corresponding foot of fall; but if the road is on a steep grade, Fig. 5, an elevation of 1 foot above the grade line or of a like amount below the grade line, literally speaking, produces no rise and fall, because in either case it is a continuous

FIG. 4.

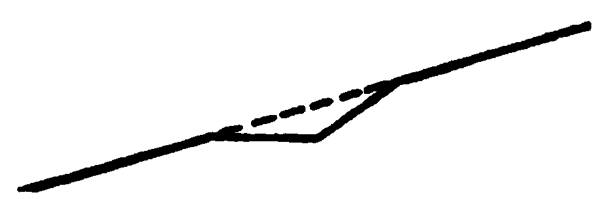


FIG. 5.

up grade. However, as far as the operation is concerned, the two cases are exactly alike, and each has a foot of rise and fall.

Rise and fall is measured by the number of vertical feet of rise, as shown by the differences of elevation on the profile.

67. The introduction of rise and fall is a question either (1) between the increased cost of operation and the increased cost of construction required to fill up the hollow or to cut down the hill, or (2) between the cost of operation of the rise and fall and of the increased distance necessary to go around the obstruction.

The following example is often cited as showing the improvement that can be made in locating roads. "An old road in Anglesea rose and fell between its extremities, 24 miles apart, a total perpendicular amount of 3,540 feet; while a new road laid out by Telford between the same points, rose and fell only 2,257 feet; so that 1,283 feet of vertical height is now done away with, which every horse

passing over the road had previously been obliged to ascend and descend with its load. The new road is, besides, more than two miles shorter. Such is one of the results of the labors of a skilful road maker." * The road may have been economically re-located, but the citation fails to show whether the increased cost of construction to eliminate rise and fall was justified by the decreased cost of operation.

The following example from the same author, also frequently quoted, shows that rise and fall was eliminated by increasing the distance, although no attempt is made to show that the increased distance was more economical than the rise and fall thereby eliminated. "A plank road, lately laid out under the supervision of Mr. Geddes, between Cazenovia and Chittenango, N. Y., is an excellent exemplification of the true principles of road making. Both these villages are situated on the Chittenango Creek, the former being 800 feet higher than the latter. The most level wagon road between these villages rises more than 1,200 feet in going from Chittenango to Cazenovia, and rises more than 400 feet in going from Cazenovia to Chittenango, in spite of this latter place being 800 feet lower. It thus adds one half to the ascent and labor going in one direction; and in the other direction it goes up hill one half the height, which should have been a continuous descent. The line of the plank road by following the creek (crossing it five times) ascends only the necessary 800 feet in one direction, and has no ascents in the other, with two or three trifling exceptions of a few feet in all, admitted in order to save expense. There is a nearly vertical fall in the creek of 140 feet. To overcome this, it was necessary to commence far below the falls, to climb up the steep hillside, following up the sides of the lateral ravines until they were narrow enough to bridge, and then turning and following back the opposite sides till the main valley was again reached. The extreme rise is at the rate of 1 foot to the rod (1 in 16½), and this only for short distances, and in only three instances, with a much less grade or a level intervening." †

68. *Classes of Rise and Fall.* In discussing the effect of rise and

* Roads and Road Making, W. M. Gillespie, p. 36. New York, 1847.
† *Ibid.*, p. 233–34.

fall upon the operation of a road a distinction must be made between three classes of rise and fall, as follows:

Class A. Rise and fall on grades at a less slope than the angle of repose (the grade on which a vehicle by its own weight will maintain a uniform speed), and so situated as not to require any addition to the total power required to move a load over the road.

Class B. Rise and fall on grades so steep as to require either the holding back of the load by the team or the application of brakes.

Class C. Rise and fall on the maximum grade.

69. An example of the first class of rise and fall is shown in Fig. 6. The team is relieved on the down grade an amount exactly equal to the extra tax upon the up grade, and the only effect upon the team is that the effort is concentrated on the up grade instead of being uniformly distributed over the road; but as the slope is assumed to be equal to or less than the angle of repose, the maximum effort is equal to or less than twice the normal. If the grade line rises above the level instead of dipping below it, the case is not changed except that the rise is a little more unfavorble, since the team has no relief before the increase in effort is required. Therefore this class of rise and fall costs little or nothing.

FIG. 6.

In the preceding examples, a change of velocity would alter the power required at any particular instant; but in wagon-road traffic the speed is always small and consequently the effect of variations of speed are quite small, and may be entirely neglected. On railroads a variation of the velocity materially affects the cost of rise and fall.

If the grade is greater than the angle of repose, the team in descending must hold back the load, which is lost energy, or brakes must be applied, which tend to destroy the road; and in ascending, the demand upon the team is greater than twice the normal. Therefore in either case this class of rise and fall adds to the cost of operating the road.

If the grade is the maximum, it may be sufficient to limit the amount of the load a team may draw over the more level portions of the road, and therefore greatly add to the cost of transportation. As a chain is no stronger than its weakest link, so a road is no better than its steepest grade.

70. *Cost of Rise and Fall.* What does it cost to develop the power required to haul a load up a grade less than the grade of repose? In other words, what is the cost of Class A rise and fall?

The cost of transportation consists chiefly of the cost of driving, of feed, and of the wear and tear on the team. Usually the cost of driving will be approximately half of the total cost of transportation; and as a team can draw a load up the grade of repose at practically the same speed, at least for short stretches, as upon the level, there will usually be no material increase in the cost of driving. Even though the team may travel slower because of the grade, the cost of the increased time can scarcely be computed because of the impossibility of determining the value of fractions of time for other purposes. The cost of feed and of wear and tear on the team must vary approximately as the total power developed. Therefore the conclusion may be drawn that rise and fall belonging to Class A will not add appreciably to the cost of transportation. This conclusion is corroborated by the popular belief that a gently undulating road is less fatiguing to horses than one which is perfectly level. The argument in support of this belief is that alternations of ascents, descents, and levels call into play different muscles, allowing some to rest while others are exerted, and thus relieving each in turn. The argument is false, and probably originated in the prejudices of man in his quest for variety, rather than in the anatomy of the horse; but the above theory would not have gained its wide popularity if a gently undulating road were appreciably more fatiguing to a horse than a perfectly level one. A perfectly level road is the best for ease of transportation.

71. If the grade is steeper or longer than that up which the team can draw the normal load by exerting twice the tractive power required on the level, i. e., if the rise and fall belongs to Class C, then the grade has the effect of limiting the load that can be drawn over the level portion of the road, and consequently increases the cost of transportation. The load which a team can draw up any grade can be approximately computed as in § 65. If the load that can be drawn up any particular grade is, for example, three fourths of the normal load on the level; then it will cost as much to haul three fourths of a load with this grade as a full load without the grade. If the cost with a grade less than the maximum is 10 cents per ton-

mile (see § 4–7 and § 20–21), then the cost with the maximum grade will be $10 \div \frac{3}{4} = 13\frac{1}{3}$ cents per ton-mile; and therefore for each ton going over the road, the maximum grade adds $3\frac{1}{3}$ cents per ton-mile. In determining the amount of traffic, only full loads should be included; but notice that the full load varies with the speed. A ton may be a full load at 3 miles per hour, while half a ton may be a full load at 6 miles per hour.

Knowing the load on the maximum grade and also the cost per ton-mile for a level road or for a grade less than the maximum, the justifiable expenditure to reduce the maximum grade may be computed as follows: The difference in cost per ton-mile with and without the maximum grade may be determined as in the preceding paragraph; and this multiplied by the annual number of loads going over the road gives the sum that may be spent annually to reduce the maximum grade to the lesser value. This sum may be used to pay interest on the cost of cutting down the hill or of filling up the hollow.

The data are so uncertain that the result must be regarded only as a rough approximation; and yet it is worth while to make an investigation as above as a guide to the judgment.

72. Class B rise and fall is intermediate between Class A and Class C, and its cost is even more difficult to compute than that of Class C. The chief difficulty is in determining the relative cost of developing power on a level and up a grade. Only an estimate can be made, and the estimate will vary greatly with the point of view. For example, farmers usually have a surplus of power (horses) as far as transportation is concerned, and therefore they would consider a slight increase in the demand for power as a matter of small moment. Again, teamsters differ greatly as to what is a proper or economical load for a horse, and also as to the effect of a temporary over-load.

There are two methods of computing the cost of this class of rise and fall, neither of which are more than roughly approximate.

1. Assume that the cost of Class B rise and fall bears the same relation to that of Classes A and C, that the grade of B bears to that of A and C. Then if the grade for Class B is only a little greater than the angle of repose, the cost is only a trifle greater than that

of Class A; and if the grade is nearly a maximum, then the cost of the rise and fall closely approximates that of Class C.

2. Assume that the energy developed on a grade over and above that required on the grade of repose, costs the same per unit as that of an equal amount of energy developed on the level. For example, assume that the rise is 1 foot more than the angle of repose; and assume that the cost of drawing a load on a good broken-stone road is 5 cents per ton-mile (see § 5–6), and that the tractive power is 40 lb. per ton. Then, moving a ton one mile will develop $5{,}280 \times 40 = 211{,}200$ foot-pounds of energy, which will cost 5 cents. The cost of one foot-pound of energy, then, is $5 \div 211{,}200 = 0.000{,}023{,}7$ cents. Drawing a ton over a rise 1 foot high develops 2,000 foot-pounds, the cost of which is $0.000{,}023{,}7 \div 2 \times 2{,}000 = 0.023{,}7$ cents. In going up the above grade, the team must develop enough power to move the load up the grade of repose and in addition must develop enough to lift the load through 1 foot vertically. Therefore the cost of the 1 foot of rise assumed above is 0.023,7 cents for each ton going over the road.

It was assumed above that the load is retarded in the descent by the application of brakes; but if the grade in question is situated in a flat country where brakes are not usually placed upon vehicles, the team must hold back on the descent an amount equal to the extra energy required on the ascent, and therefore the cost of the foot of rise and fall will be, almost or quite, doubled.

With data similar to the above, and with a knowledge of the amount of traffic, it is a simple arithmetical process to compute the sum that may be spent annually to eliminate one or more feet of rise and fall. Notice that in this case only the full loads should be considered (see the first paragraph of § 71). For example, assume that a broken-stone road has a traffic of 20 tons per day one way for 300 days of the year, or an annual traffic of $20 \times 300 = 6{,}000$ tons. The cost of a foot of rise and fall per ton of traffic is 0.023,7 cents, and the annual cost on this particular road is $0.023{,}7 \times 6{,}000 =$ \$141.70. This is the amount which, according to the above investigation, can be spent annually to cut down the hill or to fill up the hollow sufficiently to eliminate 1 foot of rise and fall.

Similarly, for an earth road having a cost of 15 cents per ton-mile and a tractive power of 100 pounds per ton, 1 foot of rise costs

0.028,4 cents, and the foot of ascent assumed above will cost 0.028,4 cents for each ton going over the road. If this road has a traffic of 5 tons one way for 300 days of the year, the annual cost of the foot of rise and fall is $0.028,4 \times 5 \times 300 = \$44.60$, which is the sum that can be spent annually to eliminate the foot of rise and fall.

From the point of view of the last solution, it appears that the cost of Class A rise and fall increases with the steepness of the grade, that is, increases as the rate of the grade approaches the angle of repose. In all probability this is correct, but all the data involved are too uncertain to warrant any further discussion of the subject here. However, the engineer should bear such relations in mind in solving a particular problem.

73. *Distance vs. Rise and Fall.* In locating a road the question may arise between the relative desirability of introducing rise and fall and of increasing the length of the line. The problem then is to determine the relative value of distance and of rise and fall.

If the conclusion in § 70 is correct, that the cost of Class A rise and fall is not appreciable, then the distance should not be increased at all to eliminate Class A rise and fall.

74. For Class B rise and fall an approximate solution can be obtained by assuming that it costs the same to develop a certain amount of energy in overcoming Class B rise and fall as to develop a like amount of energy in moving a load on a level road. This assumption is probably reasonably correct.

For example, the tractive resistance of the best broken-stone road is 33 pounds per ton, and the work necessary to raise 1 ton through 1 foot of rise is 2,000 foot-pounds; therefore to develop 2,000 foot-pounds of work on a level broken-stone road, a ton must be moved $2,000 \div 33 = 60$ feet. Hence the cost of operating 60 feet of distance on this road may be considered as equivalent to 1 foot of rise and fall. Therefore to eliminate a foot of rise and fall of Class B, the length of the road may be increased 60 feet. Table 12, page 59, gives the corresponding distance for other road surfaces.*

* The above relations are for a load transported on wheels. It may be interesting to know the corresponding relations for pedestrians. The work (energy) required of a man in walking is practically independent of the nature of the road surface. A man makes progress in walking by allowing his body to fall through a small space and then raising it again preparatory to another fall. For an average

TABLE 12.

HORIZONTAL DISTANCE EQUIVALENT TO 1 FOOT OF CLASS B RISE AND FALL.

Earth roads, muddy	(tractive resistance 200 lb. per ton)....	10 feet
" " ordinary	" 100 " " "	20 "
" " dry and hard	" 80 " " "	25 "
Stone-block pavement, best	" 40 " " "	50 "
" " " ordinary	" 80 " " "	25 "
Gravel, best........................	" 50 " " "	40 "
" ordinary....................	" 80 " " "	25 "
Broken-stone road, best	" 33 " " "	60 "
" " " ordinary	" 50 " " "	40 "
Brick on concrete..................	" 25 " " "	80 "
Sheet asphalt	" 20 " " "	100 "
Iron rails, clean	" 10 " " "	200 "

75. Apparently writers on roads have not made a distinction between the several classes of rise and fall. Herschel says: * "To determine whether it is more advisable to go over than around a hill, all other considerations being equal, we have this rule: Call the difference between the distance around on a level and that over the hill *d* (the distance around being taken as the greater), and call *h* the height of the hill. Then in case of a first-class road, we go round when *d* is less than 16*h*; and in case of a second-class road, we go round when *d* is less than 10*h*." Although not specially so stated, the above rule was plainly intended for broken-stone roads.

The above rule (which has been frequently quoted) recognizes no distinction between the several classes of rise and fall. It makes the avoidance of a foot of rise in going over a small culvert or of a foot of fall in crossing an open ditch, equally as important as the elimination of a foot of rise and fall on the maximum grade It is not possible to draw sharp lines between the several classes of rise and fall, but it is certain that there is a great difference in cost between a foot of rise and fall on a flat grade and the same quantity on the maximum or limiting grade. Notice that the above rule makes the horizontal distance equivalent to a foot of rise much less than that stated in Table 12 above.

man, the energy expended in walking 16 to 20 feet horizontally is sufficient to raise his body through 1 foot vertically. Therefore, for pedestrians 1 foot of rise and fall is equivalent to, say, 18 feet of horizontal distance.

* Clemens Herschel, Science of Road Making, Prize Essay of the State Board of Agriculture of Massachusetts, Boston, 1869, p. 207–63; revised edition, *Engineering News*, New York, 1890, p. 9.

76. Maximum Grade. The fixing of the proper maximum or ruling grade is the most important matter connected with the location of a road. To do this intelligently, the maximum grade must be considered both as an ascent and also as a descent. Viewed as an ascent, the maximum or ruling grade chiefly concerns the draught of heavy loads; and viewed as a descent, it chiefly concerns the safety of rapid traveling. In both respects, the effect of the grade in limiting the load depends upon its rate, and is practically independent of its height.

77. *As an Ascent.* The load which a team can draw over any road is determined by the length and steepness of the maximum grade; or, in other words, the length and rate of the permissible maximum grade depends upon the endurance of the team. The method of computing the load that a team can draw up any grade was explained in § 65, page 51. That investigation shows that the maximum grade varies greatly with the conditions of the surface; and that the better the surface the less should be the ruling grade. In other words, unless the maximum grade is light, the amount that can be hauled on a broken-stone road does not differ greatly from that on an earth road.

The team could probably pull the maximum load up a stretch of the maximum grade 400 to 500 feet long; and if the maximum grade does not occur too often, it could probably pull the load up a stretch two or three times as long. On long maximum grades, it is wise to provide a little stretch of nearly level grade upon which to let the team rest. In the above computation, the team is assumed to have a reserve power equal to that exerted on the maximum grade; but the power required to start the load may be four or five times the normal tractive resistance, and hence a nearly level resting place is required, so that the team may readily start the load.

78. Many of the books on roads state that if the maximum grade is long, the slope should be flattened toward the summit to compensate for the decreased strength of the fatigued horses. This recommendation is both improper and impracticable. It is improper, since it assumes that if the horse is to develop energy to lift the load up the incline, he should not work at a uniform rate. Universally the race horse goes fastest on the home stretch; and if

he is urged to his utmost speed at first, he is sure to lose the race. The recommendation is impracticable, since the topography would rarely permit the flattening of the grade at the top without increased expense, and it would not be wise to incur extra cost for this purpose.

79. If the loads are much heavier in one direction than in the other, it is permissible to oppose the lighter traffic with the steeper ruling grade.

80. *As a Descent.* Viewed as a descent, the maximum grade concerns chiefly the safety of rapid traveling. Many of the writers on roads claim that the descending grade should not exceed the angle of repose, i. e., should not exceed the inclination down which the vehicle will descend by its own weight. This limit is impracticable, since the angle of repose varies with the kind of vehicle, degree of lubrication, amount of load, size of wheels, etc. Besides, this limitation is unnecessary, since the resistance of traction increases as the speed, and in going down it is only necessary to drive faster to prevent the vehicle from unduly crowding upon the team; but of course this remedy has its limitations. Further, the speed in descending may be checked by the application of the brake; but it should be remembered that the use of the brake is detrimental to the road surface, particularly on the maximum grade.

On ordinary roads, grades twice as steep as the angle of repose are operated without inconvenience or danger. In Europe it is usually assumed that on a good broken-stone road, of which the angle of repose is about 2 or 2½ per cent, a 5 per cent grade is the maximum that can be descended safely at a trot without brakes; and, if the stretch is long, 3 per cent is considered the maximum for safety. On mountain roads having a broken-stone surface, freight wagons descend 12 per cent grades by the use of brakes, but with expert drivers.

81. *Examples of Maximum Grades for Earth Roads.* For obvious reasons there are not much data under this head. In hilly country short grades of 1 in 3 (33%) are occasionally found—particularly in a new country,—and grades of 1 in 4 (25%) are somewhat common. In comparatively flat country, grades of 1 in 8 (12½%) are not infrequent.

In improving the celebrated Holyhead road, Telford found in

old roads many grades of 1 in 6 and 1 in 7. A number of roads improved by state aid in New Jersey originally had grades of 14 per cent. Of course, only the roads having the most traffic were improved; and less frequented roads in the same locality have much greater grades.

82. *Examples of Maximum Grades on Broken-stone Roads.* In Prussia the standard is: in mountainous country 1 in 20 (5%), in hilly country 1 in 25 (4%), and in level country 1 in 40 (2½%).

In Hanover the regulations are: in mountainous country 1 in 24 (4%), in hilly country 1 in 30 (3⅓%), and in level country 1 in 40 (2½%).

In Baden the standard is: main highways 5 per cent, secondary roadways 6 per cent, and mountain roads 8 per cent.

In Brunswick the regulations are: on the plains 1 in 33⅓ (3%), in hilly country 1 in 25 (4%), and in mountainous country 1 in 18 (5½%).

In France the standard is: on national roads, not exceeding 3 per cent; departmental roads, not exceeding 4 per cent; and subordinate roads, not exceeding 6 per cent. On the great Alpine road over the Simplon Pass, built under the direction of Napoleon Bonaparte, the grades average 1 in 22 (4½%) on the Italian side, and 1 in 17 (5.9%) on the Swiss side, and in only one case become as steep as 1 in 13 (7.7%).

In Great Britain, the celebrated Holyhead road, built by Telford through the very mountainous district of North Wales, has an ordinary maximum of 1 in 30 (3⅓%), with one piece of 1 in 22 (4½%) and a very short piece of 1 in 17 (5.9%), on both of which pieces special care was taken to make the surface harder and smoother than on the remainder of the road.

On the National Pike over the Alleghenies, built before the introduction of the railroad, the maximum was 7 per cent. At an early day the New York law limited the grades of turnpikes (toll roads) to 1 in 11 (9%).

In New York on state-aid roads the nominal maximum is 5 per cent, but grades as steep as 6½ per cent have been found necessary in some cases. In New Jersey are a number of state-aid roads having grades of 7 and 8 per cent, and one of 10¾ per cent. In Massachusetts no hard-and-fast standard has been adopted for the state-

aid roads, but a few have 5 per cent grades and a considerable number have 4 per cent. It is said that on some important roads the grade can not at reasonable expense be reduced below 7 per cent.

83. In improving city streets it is often impossible to make any radical change in the grade owing to the resulting damage to abutting property, and it is always impossible to avoid the steep grade by a change of location; and consequently some city streets have very steep grades which are used with surprisingly good results. Newton, Mass., has a number of macadamized streets which have long stretches of 9 and 10 per cent grades, and has one 12 per cent grade 1,000 feet long. Waltham, Mass., has one 400-foot stretch of macadam on a 12 per cent grade, and another on a 13 per cent grade. In the Borough of Richmond (Staten Island), New York City, are several pieces of 10, 11, and 12 per cent grades, and 100 feet of 14 per cent, two stretches of 200 feet each of 16 per cent, and one piece 200 feet long of 20 per cent grade.

84. For mountain roads where the bulk of the traffic is down hill, the maximum grade is often 8 per cent and sometimes as much as 12 per cent. "Experience in heavy freighting has shown that wagons can be satisfactorily controlled in all weathers on 12 per cent grades, but they can not be safely controlled on steeper grade."

85. For pleasure driving, the grade of a good gravel or broken-stone road should, if practicable, not exceed 4 per cent. A good horse with a light buggy and two persons will easily trot up this grade, and also trot down without a brake; but with a steeper grade the strain in either direction is unduly great.

For bicycle travel, a 2 per cent grade can be ascended with comparative ease and descended with but little effort. Heavier grades, up to 5 per cent, can be ascended by the average bicycle rider without extreme effort and descended without serious danger. A 5 per cent grade should be used only when unavoidable, and steeper grades can not be ascended with reasonable effort or descended with assured safety.

86. Minimum Grade. Considering only the cost of transportation, a perfectly level road is the best; but it costs less to maintain a road upon a slight grade than one perfectly level. All roads should be higher in the center than at the sides, so as to shed the rain to the side ditches, but on any road longitudinal ruts are lia-

ble to form and interfere with the surface drainage; and therefore if the road is perfectly level in its longitudinal direction, its surface can not be kept free from water without giving it so great an inclination transversely as to expose vehicles to the danger of overturning. On a perfectly level road, every rut will hold water, which will soak into the road and soften it whether it be earth or broken stone; whereas with even a slight longitudinal grade, every wheel track becomes a channel to carry off the rain water. It is a common observation that earth roads running up hill and down dale are better to travel upon than more level ones. This is largely due to the better longitudinal surface drainage.

The harder the road material the less the necessity for longitudinal drainage of the surface. An earth road-surface is certain to wear into ruts, and hence is greatly benefited by having a longitudinal slope. Gravel and broken-stone roads are liable to wear into longitudinal ruts, and hence need longitudinal drainage. Broken-stone roads built with the hardest limestones or trap are not easily worn into ruts, and therefore the necessity for a longitudinal grade is least with this class of construction.

A longitudinal grade decreases the cost of maintenance, and the advisability of introducing a grade for such a purpose depends upon the relative cost of constructing it and upon the capitalized value of the cost of maintaining it. With earth roads the expenditures for maintenance are ordinarily too slight to justify much expense in securing a longitudinal grade; but with high class broken-stone roads, which naturally have a heavy traffic, a considerable expense to secure a slight longitudinal grade is usually justifiable. Engineers whose experience has been largely upon railroads and canals are prone to spend money to secure an absolutely level road, where a slight grade could be secured at a less expense. In filling up a hollow or cutting down a hill, the employment of a light longitudinal grade may decrease the cost of construction and also the cost of maintenance without increasing the cost of transportation (§ 68–70). The important principle to remember is that a slight longitudinal grade is an advantage; although over a long stretch of level country it may not be practicable to secure it.

The following is the minimum grade adopted by leading engineers for broken-stone roads: in England 1 in 80, or 1¼ per cent; in

France, by the Corps des Ponts et Chaussées, 1 in 125, or 0.8 per cent; in the United States 1 in 200, or 0.5 per cent.

87. CURVES. Theoretically the shortest radius of curvature allowable on roads depends upon the width of the road, and upon the maximum length of teams frequenting the road or upon the speed of the shorter teams. Since the length of a four-horse team and vehicle is about 50 feet, to permit such a team to keep upon a 12-foot roadway would require a radius of the inside of the curve of about 100 feet; on a 16-foot roadway a radius of about 75 feet would be required; and on an 18-foot roadway, a radius of about 66 feet. In France the minimum radius is as follows: on main and departmental roads of which the trackway is 20 to 22 feet wide, 165, and in extreme cases 100 feet; on principal country roads which are 20 feet wide, 50. In Saxony the minimum radius on principal roads is 82 feet, and on ordinary country roads it is 40 feet.

"On mountain roads with grades of 1 or 2 per cent, heavy teams require curves of 40 feet radius, and light ones 30 feet; and with grades of 3 or 4 per cent, heavy teams require 65 and light ones 50 feet." * "In extreme cases on mountain roads four- and six-horse teams haul maximum loads over 16-foot roads having a radius at their outer edge of 30 feet." However, in this case the roads on the curves must be level, as the rear team is expected to do all of the pulling.

88. WIDTH. Under this head will be considered primarily the width of the right of way, the width of the wheelway, or improved portion, being considered later, in the chapter relating to the particular road surface.

The legal width of right of way varies greatly in different states. In an early day, before any attempt was made to improve the wheelway, the legal width was often 100 feet, and sometimes 10 rods (162½ feet). In some of the states where land is cheap, the former width still prevails to some extent. In most of the states of the Mississippi Valley, particularly those in which the land was divided according to the system of U. S. public land surveys, the legal width of right of way is usually 66 feet. A few of these states classify the

* Prize Essay on Road Making, Clemens Herschel, Massachusetts State Board of Agriculture, Report for 1869, p. 207–63.

roads, making the less frequented ones narrower; for example, in Texas the widths of first, second, and third class roads are 60, 30, and 20 feet respectively. In the earlier settled states along the Atlantic coast, 3 rods (49½ feet) is a common width, although some of the less frequented roads are only 2 rods (33 feet) wide.

If the surface is loam or clay, a considerable width of traveled way is required that the traffic may not cut the surface up so badly when it is soft. This is probably the explanation of the 60 or 66 feet so common in the Mississippi Valley. In some of the states, for example, Illinois, the law specifies that, "if possible," a strip equal in width to one tenth of the right of way shall be reserved for pedestrians on each side between the property line and the ditch. This leaves 53 feet for the wheelway and ditches, which is probably none too much for a loam or clay road. If the ditches are deep and consequently wide, the sidewalk is usually curtailed rather than the wheelway.

In Massachusetts the roads improved by state aid usually have a width of right of way of 50 feet, and in localities where there was a possibility of space being required by an electric road they are 60 feet, the latter being considered sufficient to accommodate a double-track electric road, wagon ways, and sidewalks.

89. In England the principal roads, especially those near populous cities, are laid out 66 feet wide, 20 or 22 feet being covered with broken stone. Telford's celebrated Holyhead road, a model road for a hilly country, has a width of 32 feet in flat country and 22 feet along steep ground and precipices.

In Holland the usual width is 38 feet, of which 14 feet is improved.

In France the standard widths are as follows, to the nearest foot:

Class of Road.	Right of Way.	Width Improved.
National roads	66 feet	22 feet
Departmental roads	40 "	20 "
Provincial "	33 "	20 "
Neighborhood "	26 "	16 "

90. Cross Section. The cross section of a road depends upon the material of the road surface, and hence will be considered in the respective chapters following.

91. Placing the Line. The controlling points of a line are certain points at which the position of the road is restricted within

narrow limits and is not subject to change. These may be points where the location is governed by the necessity of providing an outlet for the traffic, or points where the position of the line is restricted by topographical considerations—such as a summit over which the road must pass, or a suitable location for a bridge.

After the reconnoissance of the locality is completed and the position and elevation of the controlling points are known, the line must be marked upon the ground. For example, assume that it is desired to run a road from *A* to *D*, Fig. 7, page 68, *D* being a pass over the ridge. If the road follows the line *A B C D*, it will have the profile shown near the bottom of Fig. 7. The average grade from *A* to *B* is 1 per cent, and from *B* to *C* 5 per cent. If it is desired to locate a road that shall have a grade no steeper than 5 per cent, we may begin at *D* and locate a line having an uniform 5 per cent grade. If is best to commence the location from *D*, since usually the slopes nearer the foot of the hills are flatter than those at the summit, and consequently there is more choice of position of the line there than at the summit. Frequently in rough country, the only controlling point fixed before beginning the location survey is the lowest pass over a ridge or mountain range.

Beginning at *D*, a line may be located either (1) by setting off the angle of the gradient on the vertical circle of a transit or on a gradienter,* and sighting upon a rod which is moved until the line of sight strikes it at the same height from the ground that the instrument is above grade; or (2) the points for the line may be found by running a line of levels ahead of the transit, and measuring the distances by which to reckon the rate of the grade. The line *D E C*, Fig. 7, has a uniform gradient of 5 per cent.

If a contour map is at hand, the line can be located approximately by opening a pair of dividers until the distance between the points corresponds to 100 feet, setting one point on the place of beginning and the other on the next lower contour, which gives a line 100 feet long with a grade equal to the distance between contours,—in Fig. 7, five feet.

The line *D F G* has a uniform grade of 5 per cent. From *H* to *A*

* Baker's Engineer's Surveying Instruments, p. 209–16.

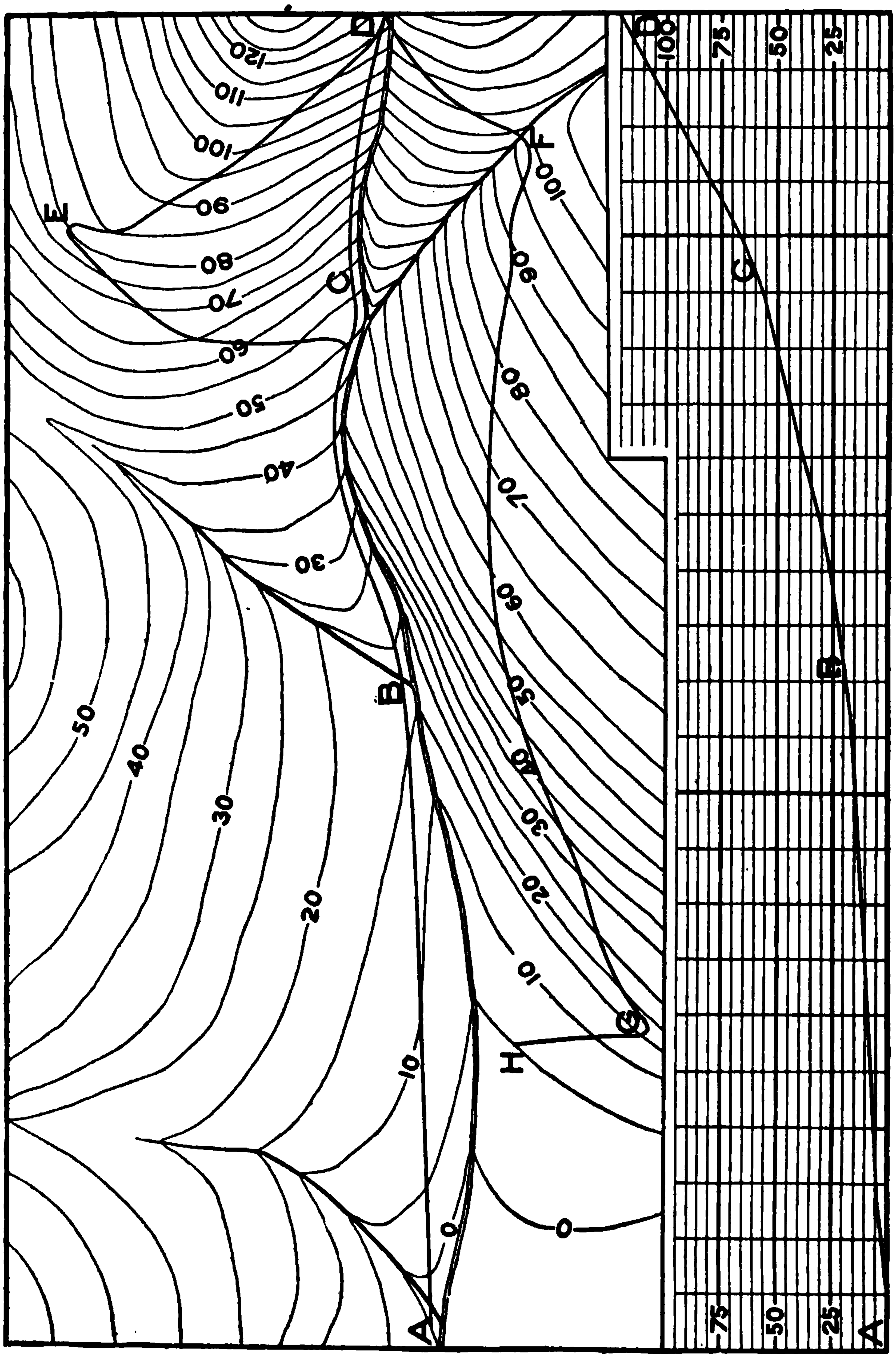


FIG. 7.—ROAD LOCATION.

the road will have considerably less grade than 5 per cent, and can have a comparatively wide range of position.

The average grade from A to D is a little less than 5 per cent, but the slopes are so steep between D and C that it is impossible, within the limits of the map, to locate such a line. If such a gradient is located from D toward A, it will necessarily make a number of short turns on itself, which, although undesirable, are sometimes unavoidable. These short turns seriously impede traffic, since vehicles can not easily pass each other on such short curves—particularly if each is drawn by a long team. Short turns are also dangerous in descending, in case control of the vehicle is lost or the team runs away.

92. The line $A\ B\ C\ D$ may be considered as an old road which it is proposed to improve by reducing the grades. Substituting the line $C\ E\ D$ for $C\ D$ changes the maximum grade from 10 to 5 per cent.

93. In placing the line attention should be given to the nature of the soil on alternative lines, since on one side of the valley the surface may be clay, upon the opposite gravel; in the bottom of the valley the soil is usually alluvial, while higher up it is generally better for road purposes. It should be remembered that in almost all steep slopes covered with loose material, the debris is either slowly moving down the slope or has attained a state of repose so delicately adjusted that an excavation for a road-bed on the inclined surface will again set the mass in motion. Such movements are particularly common in loose materials in countries where the frost penetrates deeply and the ground becomes very soft when thawing, and frequently entail long-continued and serious expense in maintenance.

If the road is to have a surface of gravel or broken stone, the relative proximity of the materials for the original construction as well as for repairs should be considered in deciding between possible locations. However, it should be remembered that after the road is completed, the amount of hauling required to supply materials for maintenance must of necessity be small in comparison with the ordinary traffic over the road; and hence this consideration should not have undue weight.

Attention should also be given to the disposal of the drainage

water, and to the question of danger from high water in the streams. For example, in Fig. 7 it is possible to locate a line on the upper side of the map with an uniform grade of 4 per cent, but such a line will lie so near the branch entering the main stream at *B* as to be in danger from floods. The matter of crossing streams should receive the most careful study. Bridges are comparatively expensive to build and to maintain.

It may be cheaper to carry the road across the gully on an embankment or a trestle than to make a detour around the head of the valley. This question can be determined by comparing the greater cost of construction of the shorter line with the capitalized value of the greater cost of operating the longer line.

In some localities the protection of the road against snow is an important matter. Deep cuts almost always catch snow; and for this reason it is sometimes better to go around a point by a supported grade than to cut through it. In a snow country roads should be located on slopes facing south and east in preference to slopes facing north and west, as the sun has greater power on the former to melt the snow.

"Nothing pays like first cost in road building," i. e., money expended in intelligent study of the location is the most economical expenditure in the construction of a road.

94. Establishing the Grade Line. After placing the center line, the topography should be taken on each side of the line for some distance—the distance depending upon the lay of the land;—and then a map should be drawn showing the line and the contours. This will serve to show whether the line is placed to the best advantage, and whether any changes are desirable. This is especially necessary over rough ground or where the line is on a maximum grade.

The center line for a final location should be carefully run and permanently marked, so that it may be re-located if necessary. A line of levels should be run and a profile drawn, upon which the grades may be established and from which the earthwork may be estimated (see § 125).

CHAPTER III.

EARTH ROADS.

95. The earth road is the cheapest road in first cost, and is by far the most common. It is a light traffic road, and only when the traffic becomes considerable is it possible to procure the money with which to improve the surface by the use of some foreign material, as gravel or broken stone. Fortunately, the best form for the earth road is also the best preparation for any improved surface. This surface, whatever its nature, is only a roof to protect the earth from the effects of weather and travel, and any preparation that will enable the native soil when unprotected to resist these elements will enable it the better to serve as a foundation for the improved surface. Because of the importance of earth roads as a means of transportation and also because of the importance of a properly formed and well-drained road-bed for all improved road surfaces, earth roads will be considered somewhat fully.

96. The term earth road will be used as applying to roads whose surface consists of the native soil, and, unless otherwise stated, it will be understood as meaning a road whose surface is loam or clay. The Construction and Maintenance of roads on loam and clay will be discussed in Art. 1 and 2, and roads on sand in Art. 3.

ART. 1. CONSTRUCTION.

97. DRAINAGE. Drainage is the most important matter to be considered in the construction of earth roads, since no road, whether earth or stone, can long remain good without it. Drainage alone will often change a bad earth road to a good one, while the best stone road may be destroyed by the absence of proper drainage. Water is the natural enemy of earth roads, for mixed with dirt it makes mud, and mud makes bad going The rain or snow softens

the earth; the horses' feet and the wagon wheels mix and knead it; and soon the road becomes impassable mud, which the frost finally freezes, the second state of the road being worse than the first—for a time at least. Further, if the water is allowed to course down the middle of the road, it will wash away the earth, and leave gullies in the surface that must be laboriously filled up by traffic or repairs. No road, however well made otherwise, can endure if water collects or remains on it. Prompt and thorough drainage is a vital essential in all road construction, and particularly so for earth roads.

A perfectly drained road will have three systems of drainage, each of which must receive special attention if the best results are to be obtained. This is true whether the trackway be iron, broken stone, gravel, or earth, and it is emphatically true of earth. These three systems are underdrainage, side ditches, and surface drainage.

98. Underdrainage. Any soil in which the standing water in the ground comes at any season of the year within 4 or 5 feet of the surface will be benefited by drainage; that is, if the soil does not have a natural underdrainage, it will be improved for road purposes by artificial subsurface drainage. It is the universal observation that roads in low places which are underdrained dry out sooner than undrained roads on high land. Underdrained roads never get as bad as do those not so drained. Underdrainage without grading is better than grading without drainage; and, in general, it may be said that there is no way in which road taxes can be spent to better advantage than in subsurface drainage. Underdrainage is the very best preparation for a gravel or stone road. Gravel or broken stone placed upon an undrained foundation is almost sure to sink (perhaps slowly, but none the less surely), whatever its thickness; whereas a thinner layer upon a drained road-bed will give much better service. Underdrained roads without gravel are better than graveled roads without underdrainage.

99. *The Object.* The opinion is quite general that the sole object of underdrainage is to remove the surface water, but this is only a small part of the advantages of the underdrainage of roads.

The most important object is to lower the water level in the soil. The action of the sun and the breeze will finally dry the surface of the road; but if the foundation is soft and spongy, the wheels will

wear ruts and the horses' feet will make depressions between the ruts. The first shower fills these depressions with water, and the road is soon a mass of mud. A good road can not be maintained without a good foundation, and an underdrained soil is a poor foundation, while a dry subsoil can support almost any load.

A second object of underdrainage is to dry the ground quickly after a freeze. When the frost comes out of the ground in spring, the thawing is quite as much from the bottom as from the top. If the land is underdrained, the water when released by thawing from below will be immediately carried away. This is particularly important in road drainage, since the foundation will then remain solid and the road itself will not be cut up. Underdrainage will usually prevent the "bottom dropping out" when the frost goes out of the ground.

A third, and sometimes a very important, object of subdrainage is to remove what may be called the underflow. In some places where the ground is comparatively dry when it freezes in the fall, it will be very wet in the spring when the frost comes out—surprisingly so considering the dryness before freezing. The explanation is that after the ground freezes, water rises slowly in the soil by the hydrostatic pressure of the water in higher places; and if it is not drawn off by underdrainage it saturates the subsoil and rises as the frost goes out, so that the ground which was comparatively dry when it froze is practically saturated when it thaws.

100. The underdrainage of a road not only removes the water, but prevents, or greatly reduces, the destructive effect of frost. The injurious effect of frost is caused entirely by the presence of water, and the more water there is in the road-bed the greater the injury to the road. The water expands on freezing, the surface of the road is upheaved, and the soil is made porous; when thawing takes place, the ground is left honeycombed and spongy, ready to settle and sink, and under traffic the road "breaks up." If the road is kept dry, it will not break up. Underdrainage can not prevent the surface of the road from becoming saturated with water during a rain, but it is the best means of removing the surplus water, thus drying the surface and preventing the subsequent heaving by frost.

That frost is harmless where there is no moisture, is shown on a

large scale in the semi-arid regions west of the Mississippi river. The ground there is normally so dry that during the winter, when it is frozen, cracks form half an inch or more wide, owing to the drying and consequent contraction of the soil, which shows that there is no expansion by the freezing of the water in the soil; and therefore in this region there is no heaving or disturbance by frost. Houses are often built on the very surface of the ground, and no trouble is ever experienced by the action of frost.

101. *The Tile.* The best and cheapest method of securing underdrainage is to lay a line of porous or farm tile 3 or 4 feet deep on one or both sides of the roadway. The ordinary farm tile is entirely satisfactory for road drainage. It should be uniformly burned, straight, round in cross section, smooth inside, and have the ends cut off square. Tile may be had from 3 to 30 inches in diameter. The smaller sizes are usually a little over a foot long,—the excess length being designed to compensate for breakage; and the larger sizes are nominally 2 or 2½ feet long, but usually a little longer. The cost of tile free on board at the factory is usually about as in Table 13, page 75. Y's for connections can be had at most factories, but they cost four or five times as much as an ordinary tile. With patience and a little experience ordinary tile can be cut to make fairly good connections.

Before the introduction of tile for agricultural drainage, it was customary to secure underdrainage by digging a trench and depositing in the bottom of it logs or bundles of brush, or a layer of broken stone; or a channel for the water was formed by setting a line of stones on each side of the trench and joining the two with a third line resting on these two. Apparently it is still the practice in some localities to use such substitutes for ordinary drain tile. Tiles are better, since they are more easily laid and are less liable to get clogged. Tiles are cheaper in first cost, even when shipped considerable distances by rail, than any reasonably good substitute, and the drains are much more durable.

Tiles are laid simply with their ends in contact, care being taken to turn them until the ends fit reasonably close. In some localities there is apparently fear that the tile will become stopped by fine particles of soil entering at the joints, and consequently it is specified that the joint shall be covered with tarred paper or something of the

sort; but in the Mississippi Valley, where immense quantities of tile have been laid, no such difficulty has been encountered. With a very slight fall or even no fall at all, tiles will keep clean, if a free outlet is provided, and they are not obstructed by roots of trees—particularly willow.

In some localities it is apparently customary to use collars around the ends of the tile to keep them in line. If the bottom of the trench is made but little wider than the diameter of the tile, or if a groove is scooped out in the bottom of the trench to fit the tile, no difficulty need be apprehended from this source.

TABLE 13.

COST AND WEIGHT OF DRAIN TILE.

Inside Diameter.	Price per 1000, f. o. b. Factory.	Weight per Foot.	Number of Feet in a Car Load.
3 inches	$10.00	5 lb.	7 000
4 "	15.00	7 "	6 500
5 "	20.00	9 "	5 000
6 "	27.00	12 "	4 000
7 "	35.00	14 "	3 000
8 "	45.00	18 "	2 500
9 "	55.00	21 "	1 800
10 "	65.00	25 "	1 600
12 "	90.00	33 "	1 000
14 "	120.00	43 "	800
16 "	150.00	50 "	600
18 "	240.00	70 "	400
20 "	300.00	83 "	330
24 "	360.00	112 "	300

102. *The Fall.* There is no danger of the grade of the tile being too great, and the only problem is to secure sufficient fall. A number of authorities on farm drainage and also several engineering manuals assert that a fall of 2½ or 3 inches per 100 feet is the lowest limit that should be attempted under the most favorable conditions; but practical experience has abundantly proved that a much smaller fall will give good drainage. In central Illinois and northern Indiana are many lines of tile having falls of only ⅛ to ¼ of an inch per 100 feet which are giving satisfactory drainage; and not unfrequently the ordinary porous tiles laid absolutely level directly upon the earth in the bottom of the trench, without collars or other covering over the joints, have given good drainage without trouble

from the deposit of sediment. Of course, extremely flat grades are less desirable than steeper ones, since larger tiles must be used, and greater care must be exercised in laying them, and there is more risk of the drain becoming obstructed; but these extremely flat grades are sometimes all that can be obtained, and such drains abundantly justify the expense of their construction.

If possible at reasonable expense, the grade should be at least 2 inches per 100 feet; and should never be less than $\frac{1}{2}$ inch per 100 feet unless absolutely necessary. On level or nearly level ground, the fall may be increased by laying the tile at the upper end shallower than at the lower.

103. *Size of Tile.* The following formula has frequently been employed to determine the size of tile:

$$Q=39.25\sqrt{\frac{f}{l}D^5}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

in which Q is the discharge in cubic feet per second; f the fall in a distance l (both in feet), and D the inside diameter of the tile in feet. The above formula may be reduced to the following more useful form:

$$V=6{,}798\sqrt{\frac{f}{l}d^5}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

in which V is the discharge in cubic feet per 24 hours, and d is the diameter of the tile in inches. Water 1 inch deep over an acre of land amounts to 3,830 cubic feet; and therefore if we divide the constant in equation (2) by 3,830, we get the following formula:

$$A=1.8\sqrt{\frac{f}{l}d^5}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

in which A is the number of acres for which a tile having a diameter of d inches and a fall of f feet in a length of l feet will remove 1 inch in depth of water in 24 hours.

Equation (1) is the formula ordinarily employed for the flow of water through smooth cast-iron pipe, and is only roughly applicable to tile. It probably gives too great a capacity for tile. However, all the factors of the problem are too uncertain to justify an attempt at mathematical accuracy. For example, we can not know with any certainty the maximum rate of rainfall, the duration of the

maximum rate, the permeability of the soil, the amount of water retained by the soil, the effect of surface water flowing onto the road from higher ground, the area to be drained, etc. The above formula is useful only in a locality where there is no local experience with tile; and its chief value consists in showing the relation between capacity and grade, and the effect of a variation in the diameter of the tile.

The object of underdraining a road is to prevent the plane of saturation from rising so near the surface as to soften the foundation of the road even during a wet time, and therefore the provision for underdrainage should be liberal; but what will be adequate in any particular case depends upon the amount of traffic, the local conditions, the soil, etc. The best practice in agricultural drainage provides for the removal of 0.5 to 1 inch of water per day; but since the side ditches will assist in removing rain water from the road, it is probable that a provision for the removal of half an inch per day is sufficient for the underdrainage of a road. If there is an underflow of water from higher ground, or if the ground is "springy," then the ordinary provisions for underdrainage should be increased.

104. It is not wise to lay a smaller tile than a 4-inch one, and probably not smaller than a 5-inch. Tiles can not be laid in exact line, and any tilting up of one end reduces the cross section. Again, if there is a sag in the line equal to the inside diameter, the tile will shortly become entirely stopped by the deposit of silt in the depression.

It is sometimes wiser to lay a larger tile than to increase the fall. Again, it may be better to lay a large tile near the surface with smaller fall than to lay small tile deeper with a greater fall. Ordinarily, the deeper the tile the better the drainage, although 3½ or 4 feet deep is usually sufficient.

105. *Laying the Tile.* It is unwise to enter upon any detailed discussion of the art of laying the tile. The individual tiles should be laid in line both vertically and horizontally, with as small joints at the end as practicable. Care should also be taken that the tile is laid to a true grade, particularly if the fall is small, for if there is a sag it will become filled with sediment, or if there is a crest silt will be deposited just above it. The drain should have a free and adequate outlet. The end of the line of tile should be protected

by masonry, by plank nailed to posts, or by replacing three or four tiles at the lower end by an iron pipe or by a wooden box.

106. *Cost of Laying Tile.* The prevailing prices for laying tile in loam with clay subsoil is about as follows: for 8-inch tile or less 10 cents per rod for each foot of depth; for 9-inch, 11 cents; for 12-inch, 14 cents; for 15-inch, 17 cents; and for 16-inch, 18 cents. To aid in remembering the above data, notice that the price is 10 cents per rod per foot of depth for 8-inch tile or less, with an increase of 1 cent for each additional inch of diameter.

The cost of a mile of 5-inch tile drain is usually from $200 to $250, exclusive of freight on the tile. If there is any considerable amount of work, the above prices for the smaller tile can be reduced 10 to 20 per cent; and often there is enough discount on the prices given in Table 13, page 75, to cover the railroad freight-charges. A tile drain is a permanent improvement with no expense for maintenance, the benefit being immediate and certain; and therefore it is doubtful if money can be spent on earth roads to better advantage than in laying tile.

107. *One vs. Two Lines.* Usually a line of tile 2½ to 3 feet deep under the ditch at one side of the road will give sufficient drainage. Some tests made by the Illinois Agricultural Experiment Station (not yet published) seem to indicate that one line will give fairly good drainage under the most adverse conditions. The experiment consisted in the drainage of a piece of land selected as the worst that could be found in a part of the state notorious as having a large area of hard-pan which it was generally considered could not be underdrained "because the soil held water like a jug." Lines of tile were laid 2½ feet deep and 50 feet apart. The water level at a point midway between the lines of tiles was lowered 18 inches, when at the same time the water level in the undrained portion of the field was only 6 inches below the surface. In this case the surface of the ground water had a slope of 1 foot in 25 feet.

A few other observations seem to confirm the above result for the slope of the surface of saturation. The exact form of the surface of saturation is not known, but it is known to be a curve slightly convex upward. The inclination varies with the nature of the soil, is most convex near the tile, and is most convex immediately after a rain and gradually thereafter approaches an inclined plane.

The traveled portion is usually not more than 50 feet wide, and therefore a single line of tile $2\frac{1}{2}$ to 3 feet below the bottom of the side ditch, if of adequate size, will give nearly perfect drainage; and a second line will not materially improve it. For example, in Fig. 8,

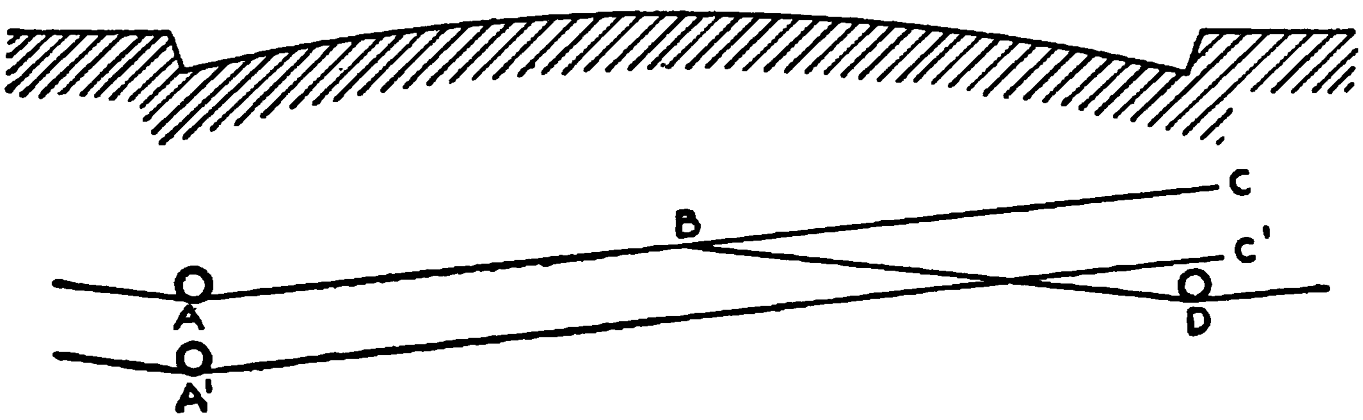


FIG. 8.

if A represents the first line of tile, the surface of the ground water is represented by the lines $A\ B\ C$. If a second line of tile, D, is laid, the water surface will be $A\ B\ D$, and the second line will drain only the comparatively small portion $C\ B\ D$. The diagram shows that a single line well below the surface is far better than two shallow ones. For example, lowering the tile A 6 inches, lowers the water surface to $A'\ C'$, which represents better drainage than the line $A\ B\ D$ with the two lines of tile.

It is generally conceded that for agricultural drainage it is sufficient to place the lines of tile 100 feet apart, provided they are of reasonable size and at sufficient depth. A tile will give agricultural drainage 50 feet on either side of it; that is, a tile under only one side ditch will give agricultural drainage of the traveled way. More thorough drainage is required for agricultural than for road purposes, since when damp most soils will pack, which is harmful to agricultural land but beneficial to a road.

108. The above seems to prove that one line of tile, if of proper size and at sufficient depth, will afford sufficient drainage for road purposes; but nevertheless it is claimed by competent authorities that two lines are sometimes required. In some localities a stratum of hard-pan near the surface makes it necessary to lay the tile so shallow that two lines are really required; and sometimes the tile is so small or so poorly laid that one line is insufficient.

In case of doubt as to whether one or two lines of tile are needed, put in one and watch the results. If both sides of the road are equally good, another tile drain is not needed. In mak-

ing these observations care should be taken not to overlook any of the factors, as, for example, the difference in the effect of the sun upon the south and the north sides of the road, the effect of shade or of seepage water, the transverse slopes of the surface of the road, etc.

109. *Location of Tile.* Some writers on roads recommend a line of tile under the middle of the traveled portion. A tile under the middle of the road is a little more effective than one at the same level under the side ditch; but the former is considerably more expensive to lay, since it necessitates more digging—whether the tile is laid before or after the road is graded. With the same depth of digging, a tile under the side ditch is more effective than one under the center of the road. Further, if the tile is under the center, there is liability of the settling of the soil in the trench, which will make a depression and probably a mud hole; and if the tile becomes stopped, it is expensive to dig it up, and the doing so interferes with traffic Finally, if the road is ever graveled or macadamized, the disadvantage of having the tile drain under the center of the road are materially increased.

Some writers advocate the use of a line of tile near the surface, on each side of the trackway. The object of placing the tile in this position is to secure a rapid drainage of the surface; but very little, if any, water from the surface will ever reach a tile so placed, since the road surface when wet is puddled by the traffic, which prevents the water percolating through the soil. It is certain that in clay or loam the drainage thus obtained is of no practical value. Many farmers have tried to drain their barns-yard by laying tile near the surface, but always without appreciable effect. The deeper the tile the better the drainage.

One writer advocates digging a trench in the middle of the road and filling it nearly full with broken stone or poles, and then filling the remainder with earth. This drain is to be connected with both side ditches by cross drains 50 feet apart. Such construction would be very expensive and practically useless.

The rapid surface drainage sought by putting a tile or its equivalent near the surface, can best be secured by giving the surface of the road a proper crown and keeping it free from ruts and holes (see § 194).

While a line of tile on one side of the road is usually sufficient, there is often a great difference as to the side on which it should be laid. If one side of the road is higher than the other, the tile should be on the high side to intercept the ground water flowing down the slope under the surface. Sometimes a piece of road is wet because of a spring in the vicinity, or perhaps the road is muddy because of a stratum which brings the water to the road from higher ground; in either case, the source of supply should be tapped with a line of tile instead of trying to improve the road by piling up earth.

110. Side Ditches. The side ditches are to receive the water from the surface of the traveled way, and should carry it rapidly and entirely away from the roadside. They are useful, also, to intercept and carry off water that would otherwise flow from the side hills upon the road. Ordinarily they need not be deep; but, if possible, should have a broad, flaring side toward the traveled way, to prevent accident if a vehicle should be crowded to the extreme side of the roadway. The outside bank should be flat enough to prevent caving.

If the road is tiled as above recommended, the side ditch need not be very large; but it should be of such a form as to permit its construction with the road machine or scraping grader (§ 142) or with a drag scraper (§ 137), instead of requiring to be made by hand. On comparatively level ground, the proper form of side ditch is readily and cheaply made with the usual road machine. An example of this form of ditch is shown in Fig. 9, page 85. If a larger and deeper ditch is required, it can still be made chiefly with the drag-scoop scraper (§ 137). For an example of a deep ditch of this form, see Fig. 10, page 85.

A deep narrow ditch is also expensive to maintain, since it is easily obstructed by the caving banks, by weeds, and by floating trash. Fortunately the shallow ditch is easy and cheap to construct and also to maintain. If it is necessary to carry water along the side of the road through a rise in the ground, it is much better to lay a line of tile and nearly fill the ditch than to attempt to maintain a narrow deep ditch. A tile is much more effective per unit of cross section than most open ditches.

111. The side ditch should have a uniform grade and a free outlet into some stream, so as to carry the water entirely away from

the road. No good road can be obtained with side ditches that hold the water until it evaporates. Much ostensible road work is a positive damage for this reason. Piling up the earth in the middle of the road is perhaps in itself well enough, but leaving undrained holes at the side probably more than counterbalances the benefits of the embankment. A road between long artificial ponds is always inferior and is often impassable. It is cheaper and better to make a lower embankment, and to drain thoroughly the holes at the side of the road. Public funds can often be more wisely used in making ditches in adjoining private lands than in making ponds at the roadside in an attempt to improve the road by raising the surface. It is cheaper and better to allow the water to run away from the road than to try to lift the road out of the water.

When the road is in an excavation, great care should be taken that a ditch is provided on each side to carry away the water so that it shall not run down the middle of the road. Every road should have side ditches, even one that runs straight down the side of a hill. Indeed, the steepest road needs the side ditch most, although it often has none. Frequently the water runs down the middle of the road on a side hill and wears it into gullies, which are a discomfort, and often dangerous, in both wet weather and dry.

In a slightly rolling country, the side ditch frequently has no outlet, and the water is allowed to accumulate at the foot of the slope and there remain until it is absorbed by the ground or seeps into a tile drain. The difficulty could be remedied by providing an inlet from the open ditch to the tile. This may be a well, walled with plank or masonry without mortar (except near the top) and having a grating in the side or top through which the water may pass. The well should be large enough to allow a man to enter it to clean it, and should extend a foot or more below the bottom of the tile. Earth roads in villages and towns are usually better provided with such inlets than country roads, but both could be materially improved at comparatively small expense by attention to this matter.

112. If it can be prevented, no attempt should be made to carry water long distances in side ditches; for large bodies of water are hard to handle, and are liable to become very destructive. Side

ditches should discharge frequently into the natural watercourses, though to compass this, it may in some cases be necessary to carry the water from the high side to the low side of the road. This is sometimes done by digging a gutter or by building a dam diagonally across the road, but both are very objectionable. A better way is to lay a tile or put in a culvert (see Fig. 55, page 210), the amount of water determining which shall be done.

It is sometimes necessary to carry water a considerable distance in the side ditches, as, for example, when the road is in excavation. This requires deep ditches, which are undesirable and dangerous; and if the grade is considerable, the ditches wash rapidly. In such cases, it is wise to lay a line of tile under the side ditch, and turn the water from the surface ditch into the tile drain at intervals. This can be accomplished readily by inserting in the line of porous tile a Y section of vitrified sewer pipe, with the short arm opening up hill. Of course, the short arm, i. e., the vertical arm, need not be as large as the body. If necessary, two or three lengths of porous tile may be added at the upper end of the Y to make connection with the bottom of the open ditch. Earth, sods, or stones can be piled around the upper end of the tile to make a dam and to hold the tile in place.

Some road engineers lay a line of tile under the side ditch, and fill the trench with broken stone, thus making the tile carry both the surface water and the underdrainage. This practice probably affords better surface drainage, but it costs more than to allow the surface water to flow away in the side ditches. This construction is sometimes defended on the ground that the broken stone prevents the wheels from striking the tile when vehicles are forced into the ditches in passing. This danger does not seem very great, and would not occur at all if the tile were laid at the proper depth; but this is sometimes impossible owing to a hard substratum.

113. As a rule side ditches will not have too much fall, but sometimes a ditch straight down a hill will have so much as to wash rapidly, in which case it is an advantage to put in an obstruction of stone or brush. In extreme cases the bottom of the ditch is paved with stones.

114. Surface Drainage. The drainage of the surface of a road is very important, and is provided for by making the surface crown-

ing and keeping it smooth. It should be remembered that water upon the surface of the road can not be carried away by the underdrains, since the water can reach them only after it has penetrated and softened the road surface. The slope from the center to the side should be enough to carry the water freely and quickly to the side ditch; and if the surface is kept free from ruts and holes, less crown will suffice than if no attention is given to keeping the surface smooth. If there is not enough crown, the water can not easily reach the side ditches; and hence the road soon becomes watersoaked.

On the other hand, the crown may be too great. If the side slopes are so steep that traffic keeps continually in the middle, the road will be worn hollow and retain the water instead of shedding it promptly to the side ditches. If the crown is too great, it is difficult for vehicles to turn out in passing each other. Again, if the earth is piled too high in the middle, the side slopes will be washed into the side ditches, which not only damages the road but also fills up the ditches. Further, if the side slopes are steep, the top of the wheel will be farther from the center of the road than the bottom, and the mud picked up by the bottom of the wheel will be carried to the top of the wheel and then dropped farther from the center of the road than it was before, each vehicle acting like a plow and moving the earth from the center toward the side of the road. With the ordinary method of caring for earth roads, more water stands on a very convex road than on a flatter one.

The slope from the center to the side should be at least half an inch to a foot, or 1 foot in 24 feet; and it should not be more than 1 inch to a foot, or 1 foot in 12 feet. If the surface is well cared for, the former is better than the latter; but in no case is it wise to exceed the latter slope.

There is considerable difference of opinion as to the exact form to be given to the surface of a roadway (see § 308–12). Some claim that it should be the arc of a circle, and others that it should consist of two planes meeting at the center and having their junction rounded off with a short curve. The first form is shown in Fig. 9 and the second in Fig. 10. Great refinement in this matter is neither possible nor important. The proper crown can be easily and cheaply constructed with the road machine or scraping grader (§ 142).

The drainage of the surface of a road is chiefly a matter of maintenance (see Art. 2 of the present chapter); and one of the most common defects of maintenance is the failure to fill the ruts and keep the surface smooth so that the water will be promptly discharged into the side ditches. A comparatively shallow rut will

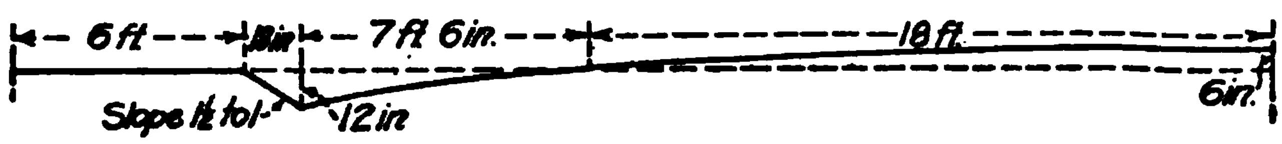


FIG. 9.—ROAD SURFACE AN ARC.

nullify the effect of any reasonable amount of crown, and wear deeper and deeper with each passing vehicle. Seldom is a mile of road seen which does not have a number of ruts and saucer-like depressions which catch and hold the water. On undulating roads, ruts and holes are naturally drained; and this is the reason why undulating roads are better than perfectly flat ones (see Minimum Grade, § 86).

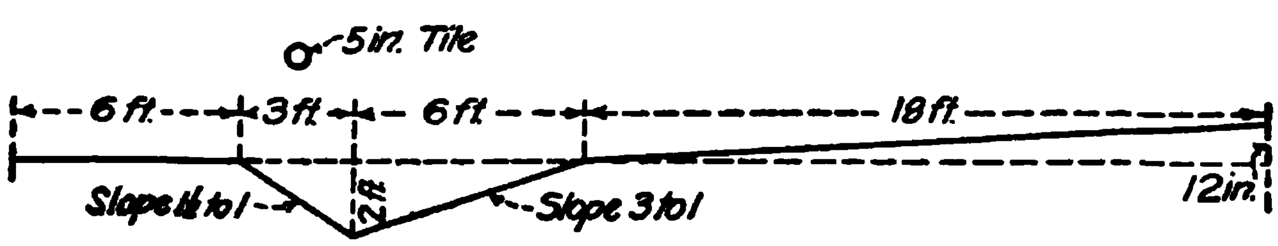


FIG. 10.—ROAD SURFACE TWO PLANES.

115. The crown should be greater on steep grades than on the more level portions, since on the grade the line of steepest descent is not perpendicular to the length of the road, and consequently the water in getting from the center of the road to the side ditches travels obliquely down the road. If the water once commences to run down the center of the roadway on a steep grade, the wheel tracks are quickly deepened, stones are loosened or uncovered, and the road becomes rough and even dangerous. Under these circumstances, it is necessary to construct catch-waters, "water-breaks," "hummocks," or "thank-you-marms" at intervals to catch the water which runs longitudinally down the road, and convey it to the side ditches, thereby preventing the formation of gullies in the road surface. These catch-waters way be either broad shallow ditches or low flat ridges constructed across the road; and they may slope toward one or both side ditches. In the former case, they should cross the road diagonally in a straight line; and in the latter

case, in plan they should be a broad angle with the apex at the center of the road pointing up hill. There is little or no difference between the merits of the ditch and the ridge, unless the bottom of the former is paved with gravel, broken stone, or cobbles. The ridges are more common, but usually are so narrow and so high as to form a serious obstruction to traffic. However, neither the ditches nor the ridges should be used except on steep grades where really necessary, since either form is at best an obstruction to travel. The angle that the catch-waters shall have with the axis of the road should be governed by the steepness of the grade—the steeper the grade the more nearly should the catch-waters run down the road. They should have a considerable breadth so that wheels may easily ascend them and horses will not stumble over them.

Catch-waters should also be constructed in a depression where an ascending and a descending grade meet, in order that they may collect the water that runs down the traveled way and convey it into the side ditches. These catch-waters should run square across the road, and should be quite shallow ditches, the bottom of which is hardened with gravel, broken stone, or cobbles.

116. Some writers recommend that a surface of the road on the face of hillsides should consist of a single slope inclining inwards (see Fig. 11). This form of surface is advisable on sharp curves, but

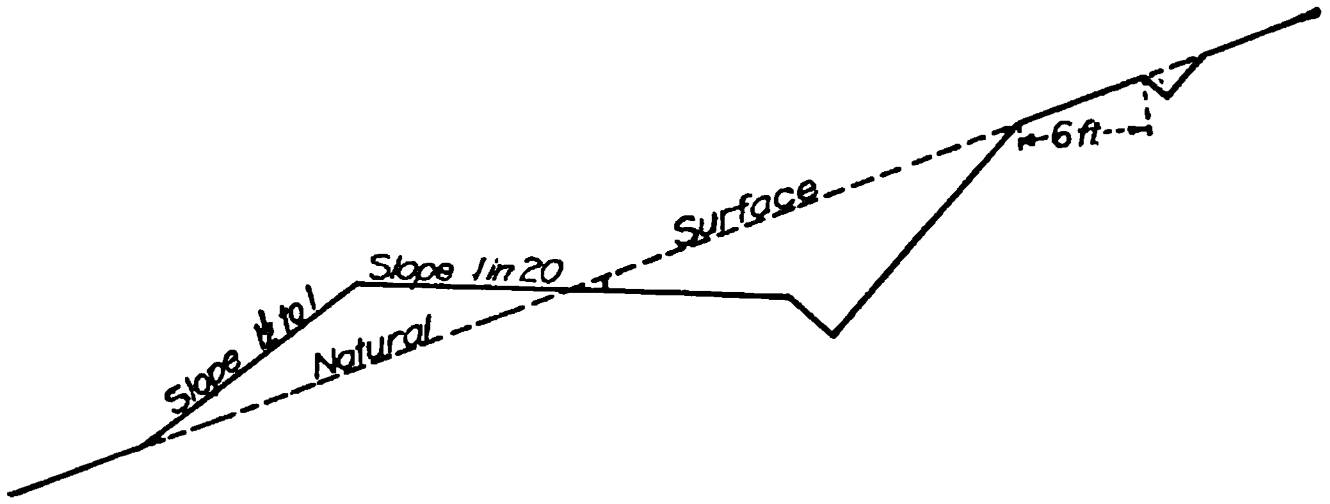


FIG. 11.—CROSS SECTION OF ROAD ON SIDE HILL.

is of doubtful propriety elsewhere. The only advantage of this form is that the water from the road is prevented from flowing down the outer face of the embankment; but the amount of rain water falling upon one half of the road can not have a very serious effect upon the side of the embankment. With a roadway raised in the center and the water draining off to either side, the drainage will be

more effectual and speedy than if the drainage of the outer half must pass over the inner half. If the surface is formed of one plane, as in Fig. 11, the lower half of it will receive the greater share of the travel; and as it will be more poorly drained, it is nearly certain to wear hollow. This will interfere with the surface drainage; and consequently a road with this section will require excessive attention to keep it in good condition. Figs. 55 and 56, page 210, show two forms of Swiss hillside roads having the center higher than either side.

Whatever the form of the road surface, if the hillside is steep there should be a catch-water above the road to prevent the water from the hillside above from flowing down on the road. Fig. 11 shows such a catch-water. It should be, say, 6 feet back from the excavation, and should have a width and depth according to the amount of water to be intercepted.

117. WIDTH OF WHEELWAY. The width of the right of way varies greatly, but is usually between 40 and 66 feet (see § 88). With a 66-foot right of way it is customary to reserve about 6 feet outside of the ditch on each side for a foot-way, and grade up the remaining 54 feet. With a 40-foot right of way it is customary to reserve 6 feet on each side for foot-ways, thus leaving 28 feet for ditches and wheel-ways. For equally good surface drainage, the greater width requires deeper ditches and more cost in construction, but permits a wider distribution of the travel when the roads are muddy or rough. The deep ditches are harder to maintain, and as a rule the native soil from the bottom of deep ditches is not so good for road building purposes as that nearer the surface. The cost of maintaining the road depends upon the amount of traffic, and is practically independent of the width. Therefore the width to be improved depends chiefly upon the width of the right of way, the character of the soil, and the climate. In a wet climate, with soil easily working into mud, a wide wheel-way is desirable; while in a dry climate, or with a soil not readily forming mud, a narrow wheel-way is preferable.

118. CROSS SECTION. The cross section or transverse contour of a road is an important matter with reference to the cost of construction and of maintenance. The cost of construction is chiefly dependent upon the form of the side ditch, and has already been

considered in § 110. The cost of maintenance depends upon the amount of crown of the surface, which has been discussed in § 114. Figs. 9 and 10, page 85, show two forms of cross section. The former has the smaller side ditch and a curved crown; the latter has a larger side ditch and an upper surface composed of two planes meeting at the center. Both may be constructed with the ordinary scraping grader (§ 142), and in both cases the side ditches furnish sufficient earth to make the crown.

Fig. 12 shows a form of cross section sometimes adopted for

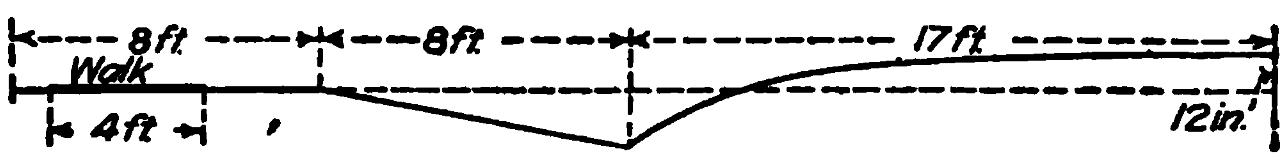


FIG. 12.—CROSS SECTION OF VILLAGE STREET.

earth roads in villages and towns. The gutter is usually made next to the sidewalk, which is objectionable, since horses must stand in the mud and water when hitched in front of the property. The form shown in Fig. 12 is free from this objection. A narrow berm is left between the sidewalk and the edge of the slope to prevent crowding the gutter too close to the shade trees, which are usually planted just outside of the sidewalk. The gutter shown in Fig. 12 decreases the available wheel-way, and consequently in some localities would be undesirable. This cross section also can be made and maintained with the ordinary scraping grader.

119. EXCAVATION AND EMBANKMENT. Side Slopes. The angle of the slopes of the cuts and fills is designated by the ratio of the horizontal to the vertical distance. Thus, if the face of the fill has an inclination of 1½ feet horizontal to 1 foot vertical, the slope is designated as 1½ to 1.

The slope of the excavations varies with the nature of the soil, being for economy as steep as its tenacity will permit. Solid rock may be cut with a slope of ¼ to 1. Common earth will stand 1 to 1, or 1½ to 1—the latter being safer and more usual. Gravel requires 1½ to 1. Some clays will stand 1 to 1, while some require a much flatter slope—in extreme cases 6 to 1. Fine sand requires a slope of 2 to 1, or 3 to 1.

The slope of embankments has less range than that of excavations, since there is less variety in the nature and the condition of the materials, and is usually 1½ to 1.

120. In both railroad and wagon-road work, it is customary to establish all earthwork slopes as planes intersecting each other in right lines. The original form is never maintained, since it is not a form of equilibrium and stability. Storm water soon washes away the angle formed by the intersection of the two plane surfaces at the top of the embankment, and the water flowing down the slope soon rounds cut the angle carefully formed at the foot. Such construction violates one of the fundamental principles of stability, and it is a needless expense to build laboriously a form of construction which nature will inevitably destroy.

The transverse contours of the embankment and excavation shown in Figs. 13 and 14 are designed to meet the above objections

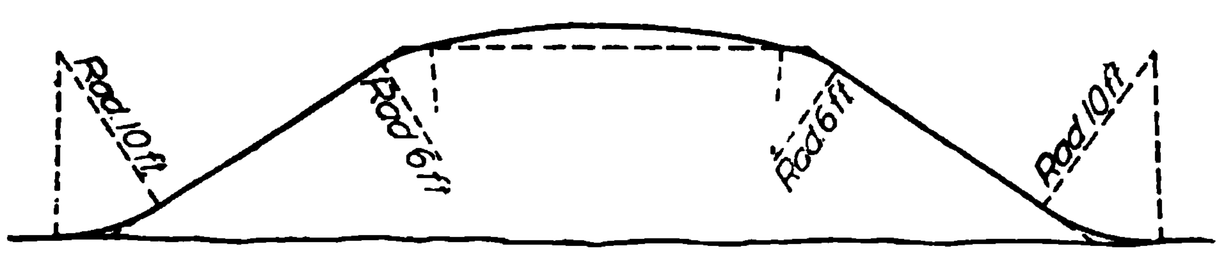


FIG. 13.—CROSS SECTION FOR EMBANKMENT.

to the ordinary forms of construction. These sections are designed in accordance with forms of railroad excavations and embankments recommended by D. J. Whittemore, the distinguished

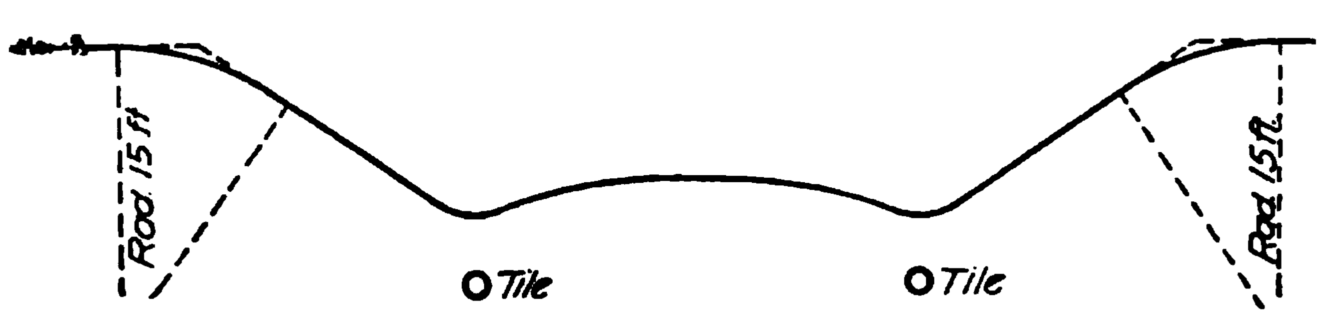


FIG. 14.—CROSS SECTION FOR EXCAVATION.

chief engineer of the Chicago, Milwaukee and St. Paul Railroad, which forms have met with the unanimous approval of leading engineers.*

It is customary in railroad construction to make the top of the earth embankment wider than the base of the gravel or broken-stone ballast, which gives a berm between the base of the ballast and the outer edge of the earth embankment. This berm has been omitted in Figs. 12 and 13, since with an earth surface there is nothing corresponding to the ballast.

* Trans. Amer. Soc. of Civil Eng'rs, Sept. 1894, Vol. 33, p. 255–66.

112. If the natural slope above the cut is long or steep, a catch-water drain should be constructed along the upper edge of the excavation slope to prevent the surface water from above from washing down over the face of the cut; but the catch-water should be well back from the edge of the excavation, to prevent the water in the drain from softening the upper angle of the slope.

The slopes of both excavations and embankments should be sowed with grass seed. Sometimes the material of the embankment is such that grass seed will not grow, in which case it may be necessary to lay sod; but of course this is very expensive. The roots of the grass will hold the earth from slipping, and prevent the face of the slope from being gullied out and washed down.

122. There is a tendency for workmen to leave the side slopes of embankments hollow and those of excavations rounding, to decrease the amount of labor required. In inspecting the work, this tendency should be borne in mind.

123. Setting Slope Stakes. For instructions as to methods of staking out the ground preparatory to beginning the work of excavating and embanking, see any of the standard volumes on railroad engineering.

124. Computing Earthwork. For the methods employed in computing the contents of excavations and embankments, see any of the various treatises on that subject; or for a briefer presentation of the subject, see books on surveying or railroad engineering.

125. Balancing Cuts and Fills. Other things being equal, the most economical position of the grade line is that which makes the amount of cuts and fills equal to each other. If the cuts are the greater, the earth therefrom must be wasted, i. e., deposited in spoil banks; and if the fills are the greater, the difference must be obtained from borrow pits,—both of which operations involve additional expense for labor and land. Sometimes it is more economical to make an embankment from near-by borrow pits than to bring the necessary material from a far-distant cut; or, vice versa, it is sometimes more economical to waste the material from a cut than to send it to a remote fill. The most economical use of the material depends upon the machinery to be used in moving the earth, the character of the earth in both cuts and fills, the road over which the earth must be transported, the cost of haul, the price of land, the

liability of cuts being filled with snow, etc.; and the matter must be decided by the engineer to the best of his judgment in each particular case.

When the road lies along the side of a hill, one side of the road is usually in cut and the other in fill; and it is customary so to place the center line that these two parts are at least nearly equal. However, where the side slopes are steep, it is better to make the road mostly in cuts on account of the difficulty of forming stable fills on steep slopes.

126. In railroad work it is the custom to balance cuts and fills on the longitudinal profile of the road, but in wagon-road work the fills as shown by the profile of the center line should be slightly in excess, to provide a place for the earth taken from the side ditches. On account of the expense, wagon-roads follow the surface more nearly than railroads; and consequently the earth from the ditches is proportionally more in wagon-road construction than in railroad construction.

127. Shrinkage of Earthwork. With most soils, the act of excavation so breaks it up that it occupies more space after excavation than before; but when the material has been placed in an embankment it will usually occupy less space than in its original position. The expansion due to excavation is usually 8 to 12 per cent of the volume, and in extreme cases may be 40 per cent; but in placing the material in the embankment, it is compacted by the weight of the embankment itself, by the pounding of the hoofs, and by the action of the wheels, until usually the final volume is less than the original.

At first thought it seems strange that earth should occupy less space when placed in an embankment than when in its original position, seeing that it is not so hard and firm, and that it will usually settle still farther after the embankment is completed. The following facts account for this phenomenon: 1. The continued action of frost has made the soil in its natural position more or less porous. 2. Earths which have been lying *in situ* for centuries become more or less porous through the slow solution of their soluble constituents by percolating water. 3. The surface soil is rendered more or less porous by the penetration of vegetable roots which subsequently decay. 4. There is ordinarily more or less soil lost

or wasted in transporting it from the excavation to the embankment.

The amount of shrinkage depends chiefly upon the character of the material and the means by which it is put into the embankment, and somewhat upon the moisture of the soil, the rainfall conditions while the work is in progress and soon afterwards, and the depth to which frost usually penetrates. If the soil is moist when placed in the bank, it will become more compact than if it were dry. Rain greatly affects the shrinkage, and embankments put up during a rainy season will be more compact than those built during a dry time. Soil from above the usual frost line is more porous than that not subject to the heaving effect of alternating freezing and thawing, and consequently shrinks more when put into an embankment.

The natural shrinkage of the ordinary soils is in the following order: (1) sand and sandy gravel least, (2) clay and clayey soil intermediate, and (3) loams most. The shrinkage according to the method of handling is in the following order: (1) drag scrapers, (2) wheel scrapers, (3) wagons, (4) cars, (5) wheelbarrows. The usual allowance for shrinkage is as follows: gravel 8 per cent, gravel and sand 9 per cent, clay and clayey earth 10 per cent, loam and light sandy earth 12 per cent, loose vegetable surface-soil 15 per cent. The above results are for ordinary earth, and do not apply to such unusual materials as "buck-shot," gumbo, very fibrous soil, etc., which have a much greater shrinkage. Solid rock will *expand* 40 to 50 per cent.

The shrinkage of earth should be considered in locating the grade lines to balance the cuts and fills.

128. Settlement of Embankments. The shrinkage of earthwork referred to above takes place chiefly during construction, but the continued action of the weight of the embankment and the effect of rain and traffic will usually cause a comparatively small settlement after completion. Sand or gravel embankments built with wheel scrapers will usually settle 1 to 2 per cent after completion, and clay or loam embankments about 2 to 3 per cent. With drags crapers the settlement will usually be a little less than the above; and with dump carts or wagons, a little more. With wheelbarrows the settlement is usually about 10 per cent, but may be as much as 25 per cent, depending upon the moisture in the soil, the

rain during construction, and the length of time under construction.

The settlement of the embankment after completion should be taken into account when determining whether the bank has been raised to the proper height. The embankment should be built to such a height that after it has ceased to settle it will be at grade. The length of time required for this settlement depends upon the weather conditions. The proper adjustment of the height of the embankments to compensate for future settlement is an important matter with broken-stone roads and with pavements.

129. The above remarks about settlement do not apply to embankments built with the elevating grader (§ 149). The settlement of earth roads put up by these machines is of no importance, and depends upon the amount of rolling they receive.

130. Rolling the Embankment. Many writers on roads recommend the rolling of all new earth embankments. In view of the usual settlement of banks built with drag or wheel scrapers, it does not appear that rolling with a farm roller would be very effective, and a heavier roller is seldom available. Simply rolling the top of the finished bank is not worth much, since the effect of the roller does not reach very deep; and, besides, no roller will compact loose earth so that wheels and hoofs will not make depressions in it.* Further, it is not practicable to roll the bank during the progress of construction, except when the scraping and elevating graders are used. Finally, those who travel the road most are generally the ones who pay for the construction, and almost universally they prefer to compact the earth by traffic.

It is customary to roll the foundation of pavements, but the chief object of so doing is to discover soft places rather than to consolidate the surface; and, besides, the foundation of a pavement is protected from rain and the action of wheels, and therefore the effect of the rolling is permanent, while with an earth road it is not.

131. Over-haul. When earthwork is done by contract, the bid includes the cost of removing excavated material and depositing it in embankments, provided the necessary length of haul does not exceed a specified limit. When the material must be carried be-

* The heaviest steam rollers give a pressure of about 600 pounds per linear inch, while wagons frequently give twice as much and occasionally three times.

yond this limit. the extra distance is paid for at a stipulated price per cubic yard per 100 feet of haul. This extra distance is known by the name of "over-haul" or simply "haul." For an explanation of the method of computing "haul," see treatises on earthwork or books on railroad surveying.

The specified limit, i. e., the distance of free haul, depends upon the conditions. It is sometimes made as low as 100 feet, and is sometimes 2,000 feet—the latter usually only in street work. In railroad work 500 feet is a common limit.

132. Frequently all allowances for over-haul are disregarded. The profiles, estimates of quantities, and the required disposal of material are shown to bidding contractors; and they must then make their own allowances, and bid accordingly. This method has the advantage of avoiding possible disputes as to the amount of the over-haul allowance, and is adopted by some railroads on this account.

133. Stability of Embankments. The principles to be observed in the formation of an embankment depends somewhat upon the machinery employed in doing the work, but a few general considerations are not out of place here.

Specifications usually require that "all matter of vegetable nature must be carefully excluded from the embankment." It is impracticable to do this when the road passes through grass land—particularly if the grade is built with a "road machine" or "road grader" (§ 142). It is desirable to remove brush, tall grass, and high weeds from the space to be occupied by the embankment and the borrow pit; but small twigs, leaves, and sod are no material detriment, and their removal is a needless expense—except at the point where the road passes from cut to fill. It is essential that all vegetable matter and loose porous soil should be removed at this point, otherwise there will be a soft place ready to soak up water which will make a mud hole and also weaken the bank just below it. When an embankment is to be made across a swamp, bog, or marsh, the site should first be drained as thoroughly as possible. After this is done, if any considerable amount of soft oozy matter remains, it should if possible be removed, and the embankment started on the hard bottom. If the soft matter is deep, it may be necessary to lay a foundation of logs or fascines to support the earthwork.

Perfect solidity should be the leading object aimed at, and all necessary precautions should be taken to prevent or lessen the tendency of the bank to slip. To secure stability, embankments should be built in successive layers not more than three or four feet thick, and the vehicles conveying the materials should be required to pass over the bank, so as to consolidate the earth. Specifications sometimes state that the layers shall be made concave upwards, but this refinement is scarcely ever necessary, although it is well to see that the layers are never very much convex upward. Embankments are sometimes first built up in the center, and afterwards widened by tipping or dumping earth over the side; but this should never be allowed.

When embankments are to be formed on sloping ground, it may be necessary to plow the ground or to cut steps in the rocky surface to hold the filling from sliding down the natural surface. In many cases where roads are to be constructed along steep slopes, it is found cheaper to use retaining walls (§ 181) to sustain the road upon the lower side and the earth-cutting on the upper side than to cut long slopes or form high embankments.

134. IMPROVING OLD ROADS. Country roads may be improved in any of several ways:

1. By changing the location, to secure better alignment or lower gradients. The method of doing this has been discussed in Art. 2, Chapter I.

2. By cutting down the hills and filling up the hollows, to secure easier gradients. A hill may be cut down without seriously interfering with traffic by cutting one side of the roadway down a foot or two with drag or wheel scrapers (§ 141), and then turning traffic on this portion and lowering the other side, continuing to cut down each side alternately until the desired depth is reached. If the earth is deposited upon the embankment in the hollow, the traffic will consolidate the road as it is built up, which is very desirable.

3. By laying tile and cutting open ditches, to improve the drainage, as has been discussed in § 98–113.

4. By re-forming the surface by the use of the scraping grader, to improve surface drainage, as discussed in § 145–46.

5. By adding sand or gravel to a clay road, or clay to a sand road, to improve the surface. When dry, clay makes a very hard

and durable surface; but it absorbs water quite freely from above, and is so impermeable that it is not easily drained from below, consequently clay roads are very bad during a wet time. Clean coarse sand or small gravel mixed with the clay will form a hard surface that is nearly impervious to water, and consequently is not readily softened by it. Sand may be laid on in thin layers and left to be worked in by traffic; or it may be worked in with a harrow or cultivator and then rolled. Cinders may be used in a similar manner; but pebbles, the largest of which are about the size of a pea, are best for this purpose. They should be laid on in a two-inch layer and then rolled, the roadway being previously sprinkled if it is not already soft. After applying and rolling in a layer of pebbles, the road should be opened to traffic for a month or two, after which another layer should be added. Three or four layers will make a road fairly good except during a long-continued wet time. Each layer will improve the surface, but this method of hardening the surface should not be confounded with the method of constructing gravel roads discussed in Chapter III.

135. Road-building Machinery. In recent years there has been a great advance in the machinery employed in building earth-roads. The wheelbarrow was formerly much used for short hauls, but has been superseded by some form of drag scraper (§ 137) drawn by horses, and is never used now except for very small jobs, or in wet and swampy places. Formerly an embankment was constructed with plows and drag scrapers (Fig. 15, page 97), while now it is built much more cheaply and better with either the "road machine," "road grader," scraping grader (Fig. 24, page 102), or with the elevating grader (Fig. 35, page 110). Years ago earth was thrown into wagons or carts by hand and hauled to its destination, while now it is moved with wheel scrapers (Fig. 21, page 101). Earth was formerly moved considerable distances with the drag scraper, while now the wheel scraper is employed. Formerly the surface of the excavation was finished with the drag scoop-scraper, while now it is done much better and more cheaply with the tongue scraper (Fig. 18, page 98) or the scraping grader.

There are a variety of plows, dump carts, wagons, etc., used in moving earth, which need not be considered here. The dump cart is much in favor in the New England States, but is never used in the

Mississippi Valley. The steam shovel and dump cars afford the most economical method of handling earth when the amount to be moved justifies the outlay for the plant; but as that would seldom be the case in highway work, this method will not be considered.

136. Scrapers. Scrapers are generally used to move material after it has been loosened by plowing. There are two principal kinds—the drag and the wheel scraper.

137. *Drag Scrapers.* There are three forms of the drag scraper —the scoop (Fig. 15), the flat-bottomed pole-scraper (Fig. 18, page 98), and the buck scraper (Fig. 19, page 99).

138. The scoop scraper, Fig. 15, is made in three sizes. The

FIG. 15.—DRAG SCOOP SCRAPER.

FIG. 16.—SCRAPER WITH RUNNERS.

FIG. 17.—SCRAPER WITH DOUBLE BOTTOM.

smallest, for one horse, has a capacity of 3 cubic feet; and the two larger sizes, for two horses, have a capacity of 5 and 7 feet respectively. Some have metal runners on the bottom, Fig. 16, and others have practically a double bottom, Fig. 17, which decreases draft and increases durability. The best forms without runners cost about $6.00, $6.50, and $7.00 for the different sizes respectively. Runners do not add more than 50 cents to the above prices, and the double bottom, not more than $1.00.

The scoop scraper is much used for moving earth short distances; but with it there is difficulty in building a bank of uniform solidity, since each scraperful is deposited in a compact mass by itself, with low loose places between them. Nor is the scoop scraper suitable for finishing an embankment, since the surface made with it is a succession of humps and hollows which is very trying to drive over

when dry, and when it rains the low places fill with water which speedily softens the remainder of the road, and finally produces mud holes. The tongue scraper (§ 139) is much preferable for finishing the surface.

The scoop scraper is sometimes employed in loading wagons. This is done by building an elevated platform under which the wagons are driven, and to the top of which the earth is drawn in a scoop scraper upon an inclined runway. In the middle of the platform is a hole through which the scraper is dumped. To decrease the height of the platform, the trackway under the platform is excavated. This arrangement of platform and runways is called a trap.

139. The pole or tongue scraper, Fig. 18, is ordinarily used for leveling up the road surface in excavations, and is frequently employed in preparing the subgrade for pavements. It may be

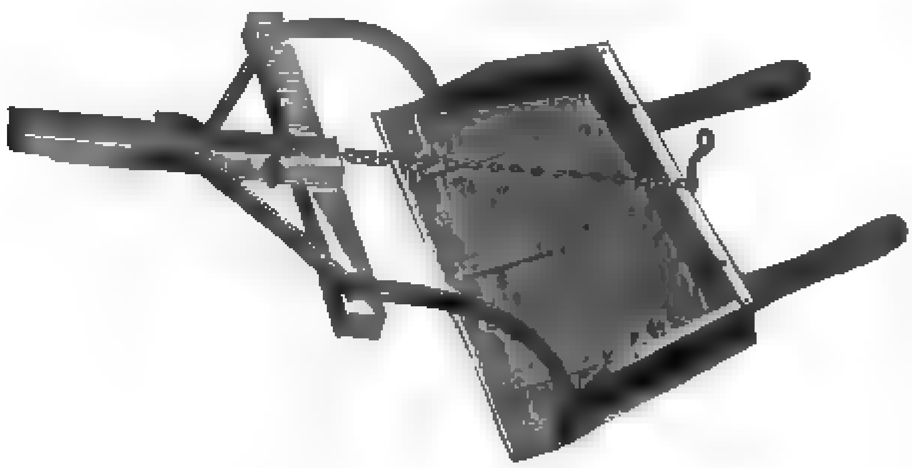


FIG. 18.—TONGUE SCRAPER.

used to transport earth short distances, but is not so good for this purpose as the scoop scraper. It is made in two sizes, 36 and 48 inches wide, which cost about $6.00 and $7.00 respectively, f. o. b. factory.

140. The buck scraper, Fig. 19 and 20, is the outgrowth of experience in irrigation, and has some advantages over the common scoop scraper. (1) The proportions of the buck scraper are such that it is more readily loaded to its full capacity. (2) It distributes the earth on the bank better, as it can be adjusted to deliver in layers from 1 to 12 inches thick. (3) The runners make it more durable. (4) It is more easily loaded. (5) It will follow up a steep bank without dumping, and hence runways are not required.

Buck scrapers are made in three sizes, the cutting edge being $3\frac{1}{2}$ feet, 4 feet, and 5 feet; and their respective capacity is 8, 10, and 12 cubic feet.

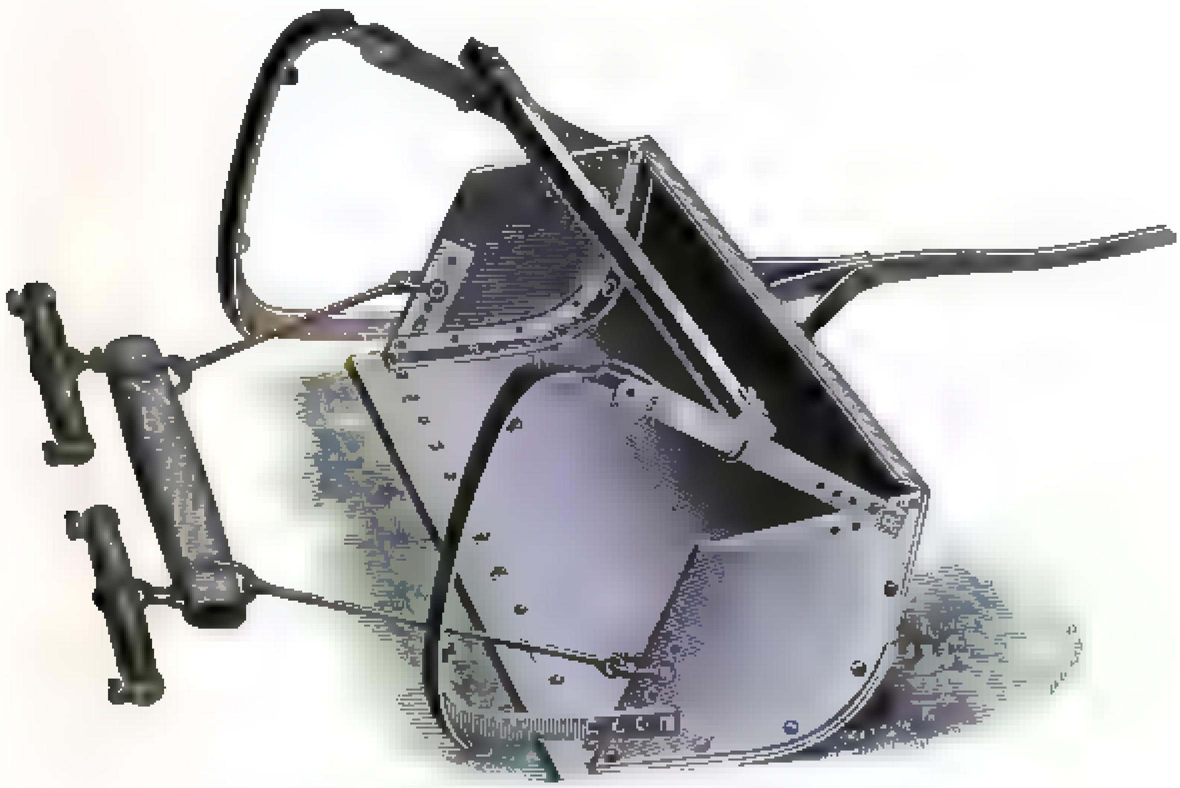


FIG. 19.—BUCK SCRAPER, READY FOR LOADING.

FIG 20.—BUCK SCRAPER, DUMPED

Under favorable conditions this form of scraper will push considerable earth along in front of it, and consequently the capacity

is frequently stated as much greater than that given above. The cost is usually about $17, $18, and $19 respectively.

141. Wheel Scrapers. The wheel scraper consists of a steel box mounted on wheels and furnished with levers for raising, lowering, and dumping. All of the movements may be made without stopping the team. The wheel scraper is made in three sizes, No. 1, 2, and 3, having a capacity of 9, 12, and 16 cubic feet respectively. Some manufacturers make an automatic front end-gate which adds materially to the load the scraper will carry, particularly on a rough down-hill road.

Fig. 21, 22, and 23, page 101, show the three positions of the scraper. The forms shown have square-end boxes, but some manufacturers make a pressed round-end scoop. Some varieties have dirt-proof hubs, and there are also a variety of styles of wheels.

The cost of the three sizes at the factory is about $25, $30, and $40 respectively, varying somewhat with the details of construction.

142. Scraping Grader. The machine shown in Fig. 24 and 25, page 102, is indifferently called a road machine or road grader, but it will here be called the scraping grader to distinguish it from the elevating grader (§ 149) and from other road machines. The scraping grader is a very important factor in caring for earth roads; and as an instrument of maintenance has been called a road hone, but could more properly be called a road plane.

143. There are several forms of scraping graders of the type shown in Fig. 24 and 25, which differ in minor details but all of which accomplish substantially the same work. Each consists of a frame carried on four wheels, supporting an adjustable scraper-blade, the front end of which plows a furrow while the rear end pushes the earth toward the center of the road or distributes it uniformly to form a smooth surface. The blade can be set at any angle with the direction of draft, or at any height; and it may also be tilted forward or backward. This machine will work in almost any soil—even where a plow will not. It is hauled by horses, and makes successive rounds or cuts until the desired depth of ditch and crown of road is obtained.

Fig. 26 to 33, pages 104 to 108, show the various kinds of work that may be done with this type of machine.

Note in Fig. 28, page 105, that the front and rear wheels do not

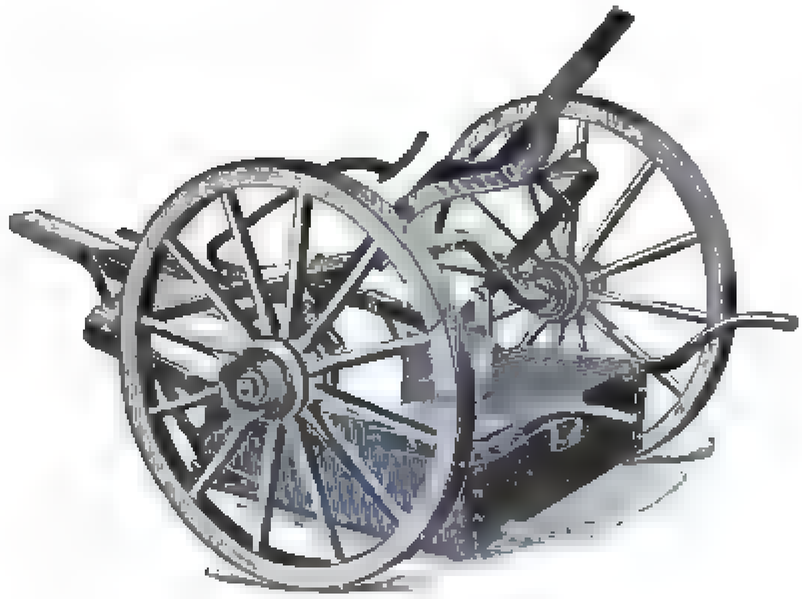


FIG 21.—WHEEL SCRAPER, FILLING.

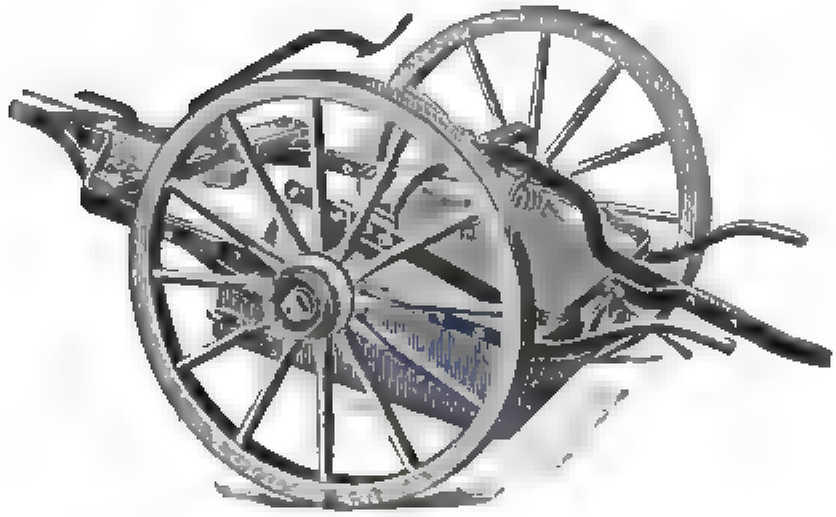


FIG. 22.—WHEEL SCRAPER, CARRYING.

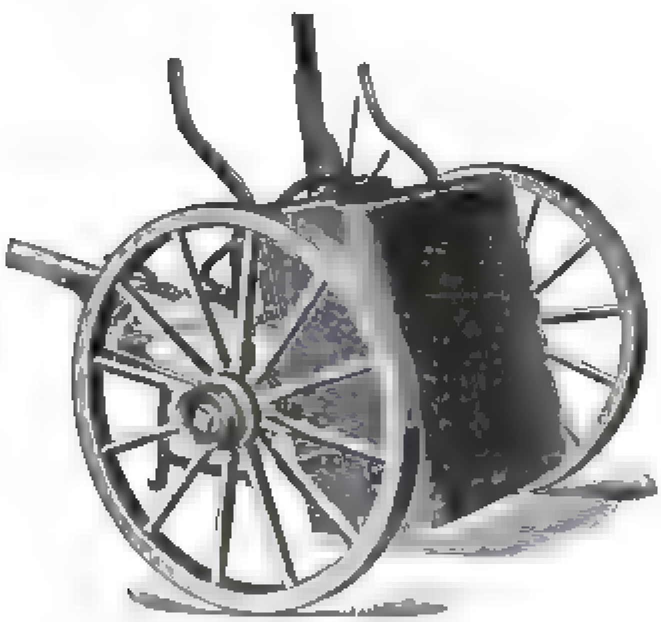


FIG. 23.—WHEEL SCRAPER, DUMPING.

track. The whole rear end of the machine may be thrown to one side or the other by operating a hand-wheel. The object of this adjustment is to neutralize the lateral resistance of the earth to being pushed sidewise by the blade. In some forms of the scraping

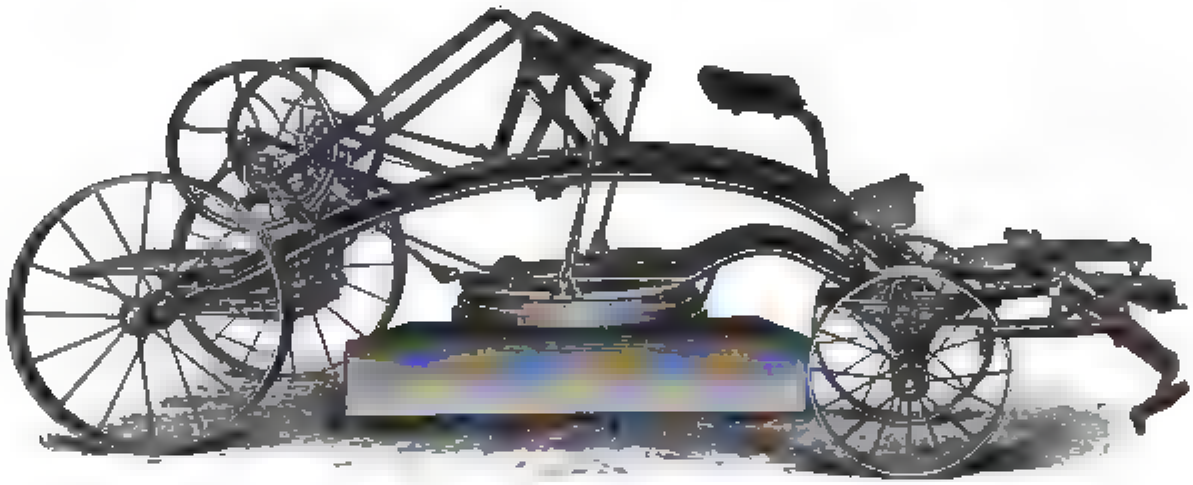


FIG. 24.—AUSTIN SCRAPING GRADER.

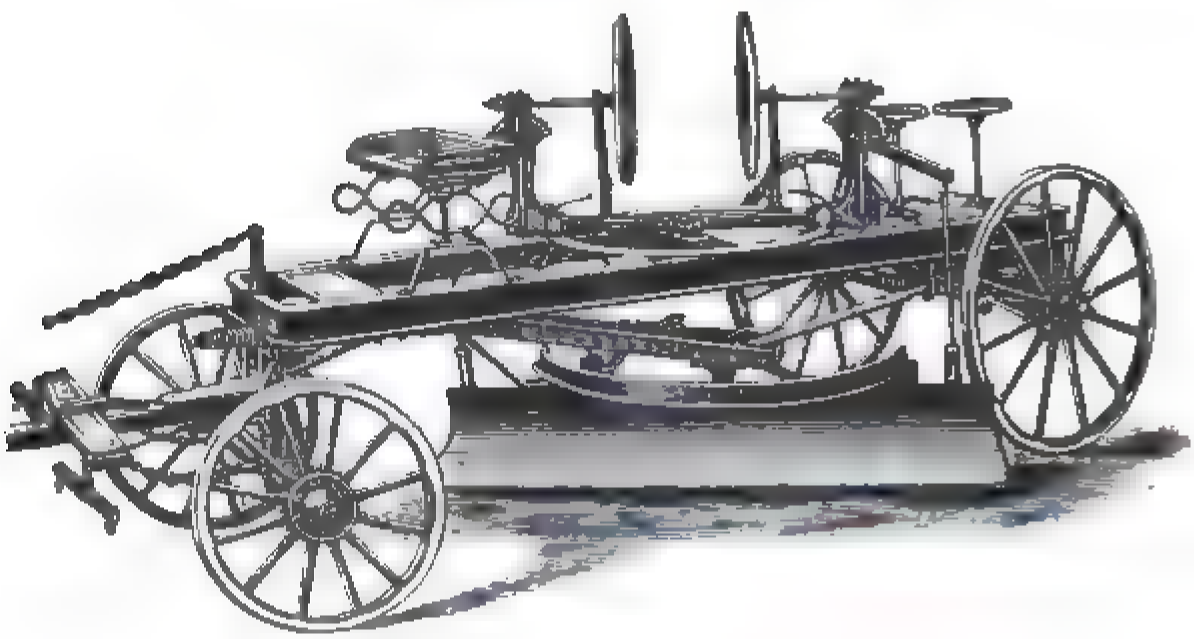


FIG. 25.—CHAMPION SCRAPING GRADER.

grader, substantially the same object is accomplished by shifting the rear axle lengthwise so that one rear wheel bears against the unplowed bank of the ditch (see Fig. 33, page 108); and in other forms the rear axle is telescoping, and either rear wheel can be moved in or out independently. Fig. 34, page 109, shows another method of neutralizing the lateral resistance of the earth. Either the front wheels or the rear one may be set at any inclination by operating a hand-wheel. The inclined wheel not only gives a com-

ponent to resist the lateral thrust of the earth, but also prevents the binding or cramping of the hub on the axle which occurs in machines having vertical wheels. The machine with inclined wheels has very recently been placed upon the market.

The preceding forms of scraping grader cost $225 to $250 at the factory. This machine is of inestimable value in constructing and maintaining earth roads, as it does the work better and much cheaper than it can be done either by hand or with plows and scrapers. The work done with the scraping grader is also superior to that done with plows and drag scrapers, since the plow cuts deeper in some places than others and these places are left full of loose earth and soon form holes which catch and hold water.

144. In addition to the type of grader shown in Fig. 24, 25, and 34, pages 102 and 109, there is on the market a cheaper and lighter machine which differs from the forms shown chiefly in having wooden wheels and frame, and less elaborate adjusting devices.

All of the forms referred to above have four wheels, but there are also upon the market several varieties consisting of a blade carried by only two wheels. As this form of machine is more suitable for use in maintenance than in construction, its consideration will be deferred to Art. 2, Maintenance (see § 200).

Still another form of scraping grader is shown in Fig. 62, page 219. It is primarily a land-leveling machine. It differs essentially from scraping graders in having a digging or plowing apparatus in front of the scraping blade, and in having adjustable aprons at each end of the blade that may be employed to prevent the earth from sliding off at the end of the blade. The scraping blade is adjustable in both the vertical and the horizontal plane. The price is $125 f. o. b. factory.

145. *Operating the Scraping Grader.* To build a road with the scraping grader, first plow a light furrow with the point of the blade, where the outside of the ditch is to be (see Fig. 26, page 104). To make the blade penetrate hard or stony ground, elevate the rear end considerably and use only the point. On the second round, with the front and rear wheels in line (see Fig. 27), drive the team so that the point of the blade will follow the furrow made the first round, plowing a full furrow with the advance end of the blade, and dropping the rear end somewhat lower than before. The third time

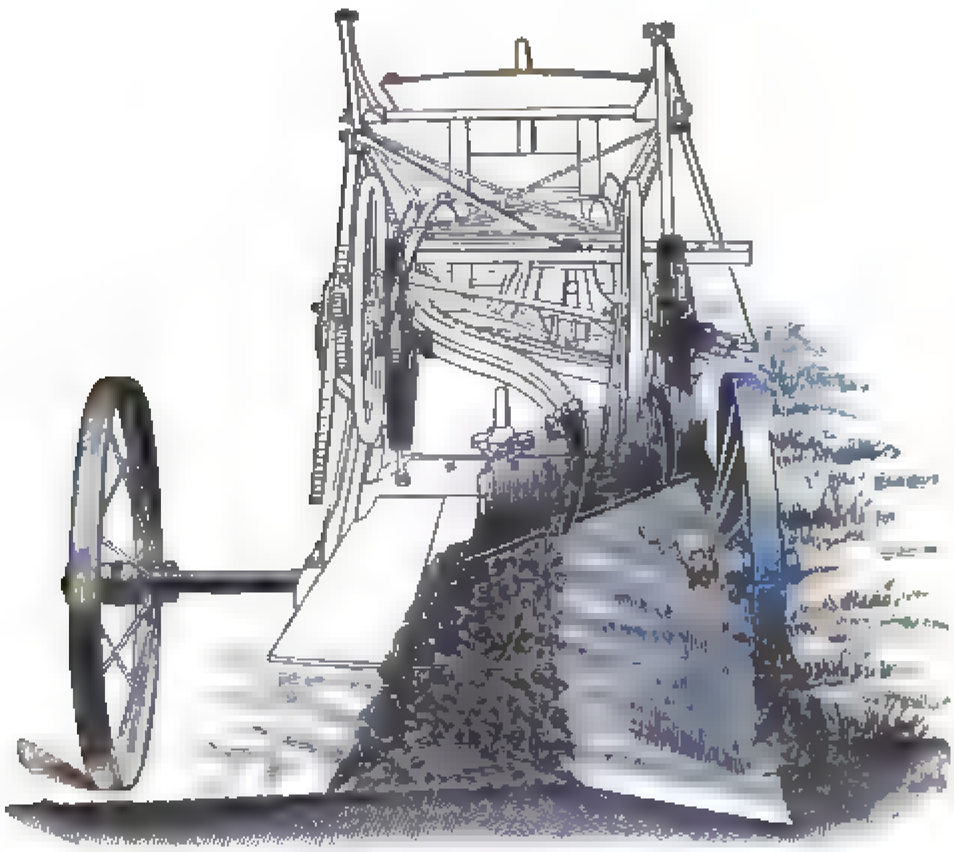


FIG. 26.—SCRAPING GRADER MAKING FIRST ROUND.

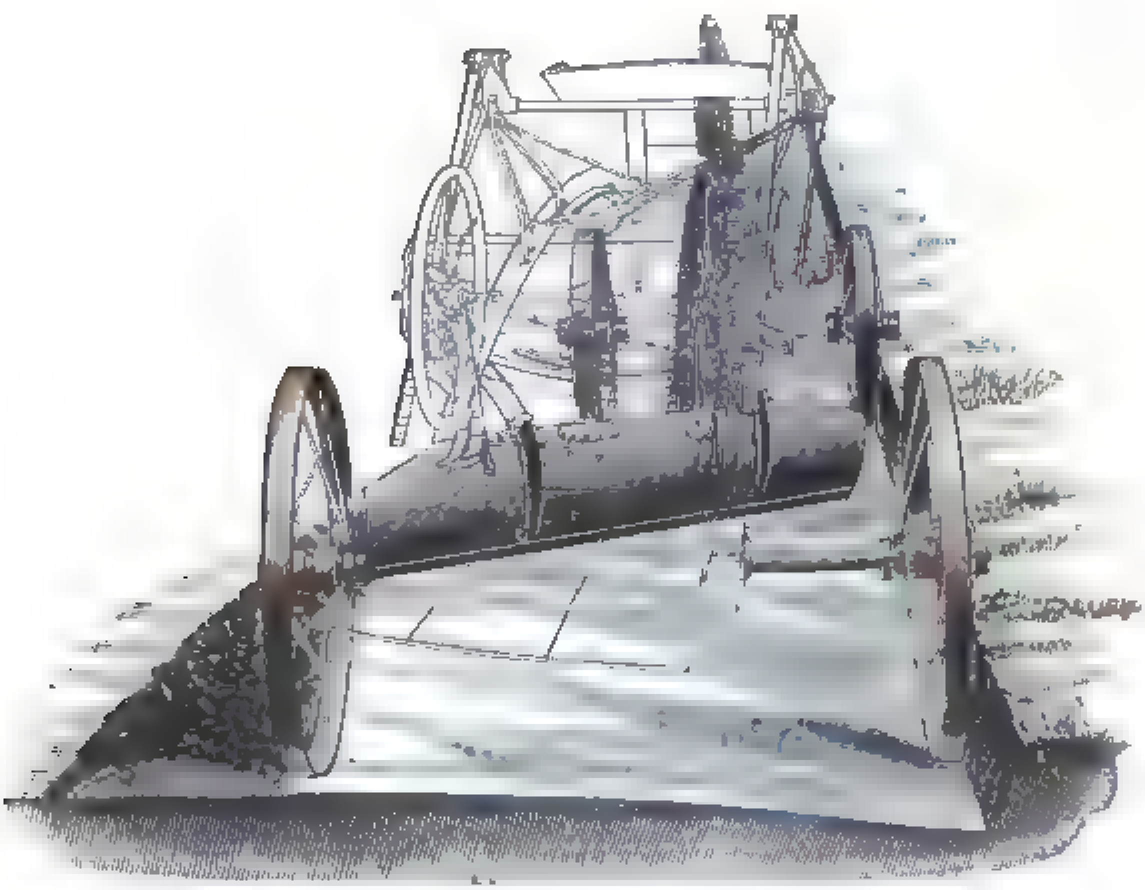


FIG 27.—SCRAPING GRADER MAKING SECOND ROUND.

round, move over toward the middle of the road the earth previously plowed. In moving the earth toward the center of the road, elevate the rear end of the blade to allow the earth to distribute under it, so as to build the road at the side of the proper crown before filling the center (see Fig. 28); and if the machine slides side-

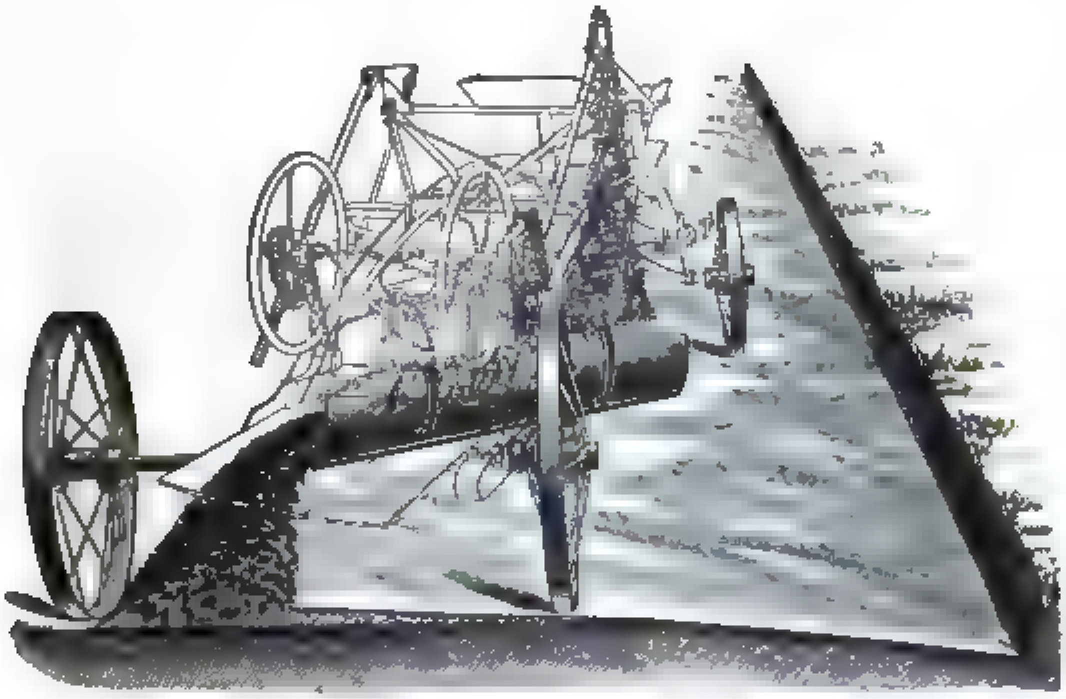


FIG. 28.—SCRAPING GRADER MAKING THIRD ROUND.

wise instead of pushing the ridge of earth toward the center, either slue the whole rear end of the machine toward the center, or move one hind wheel or the whole rear axle laterally until the rear wheel bears against the bottom of the unplowed bank at the ditch—according to the construction of the machine (see Fig. 28 and 33, page 108). If the newest form of scraping grader (Fig. 34, page 109) is employed, there will be no tendency to slip. Finally, return to the ditch and plow it out deeper, moving the earth over toward the middle whenever as much is plowed as the machine can move at once. Repeat this until the ditches are of the proper depth, and the road as full and round as required.

A ridge should not be left in the middle of the road. Usually a skilful handling of the machine will prevent the formation of such a ridge by elevating the rear end of the scraping blade, thus allowing the earth to loose out under it as the center of the road is approached. If the road is very rough, it may not be possible to fill all the ruts without forming a ridge in the center of the road at some places.

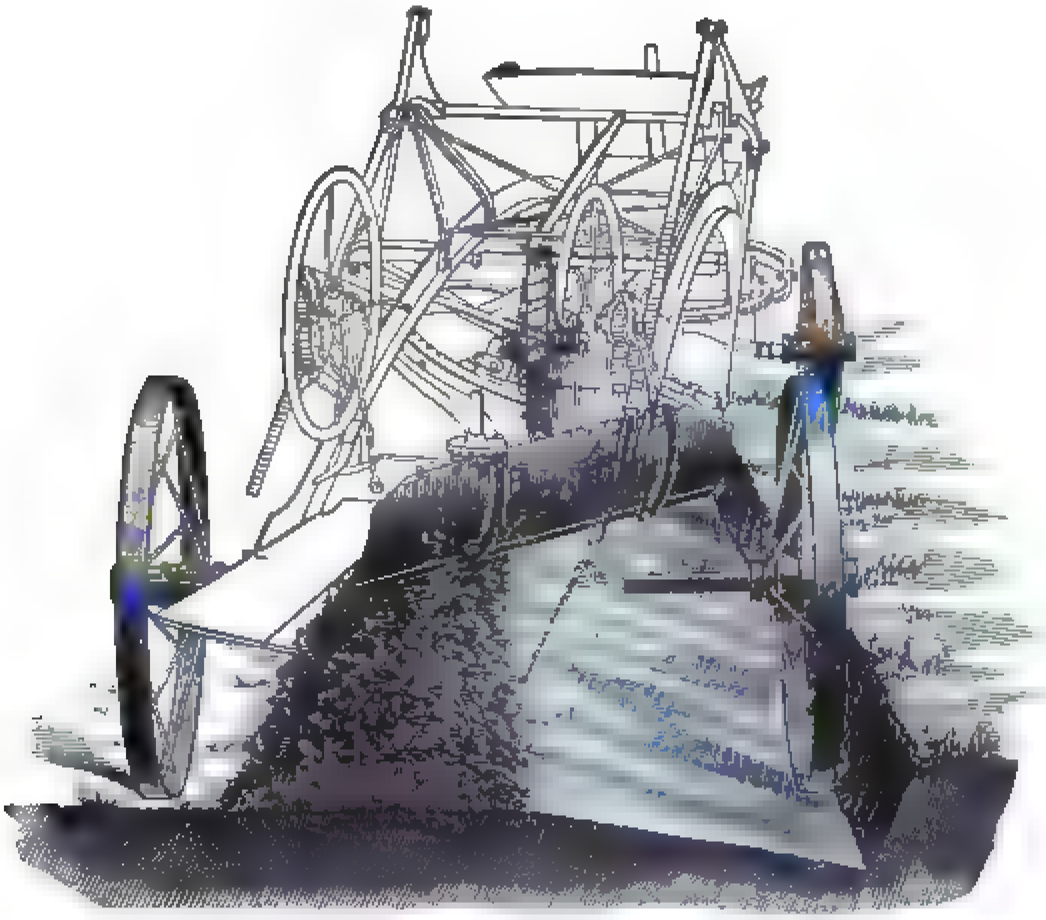


FIG. 29.—SCRAPING GRADER PLOWING BETWEEN FRONT WHEELS.

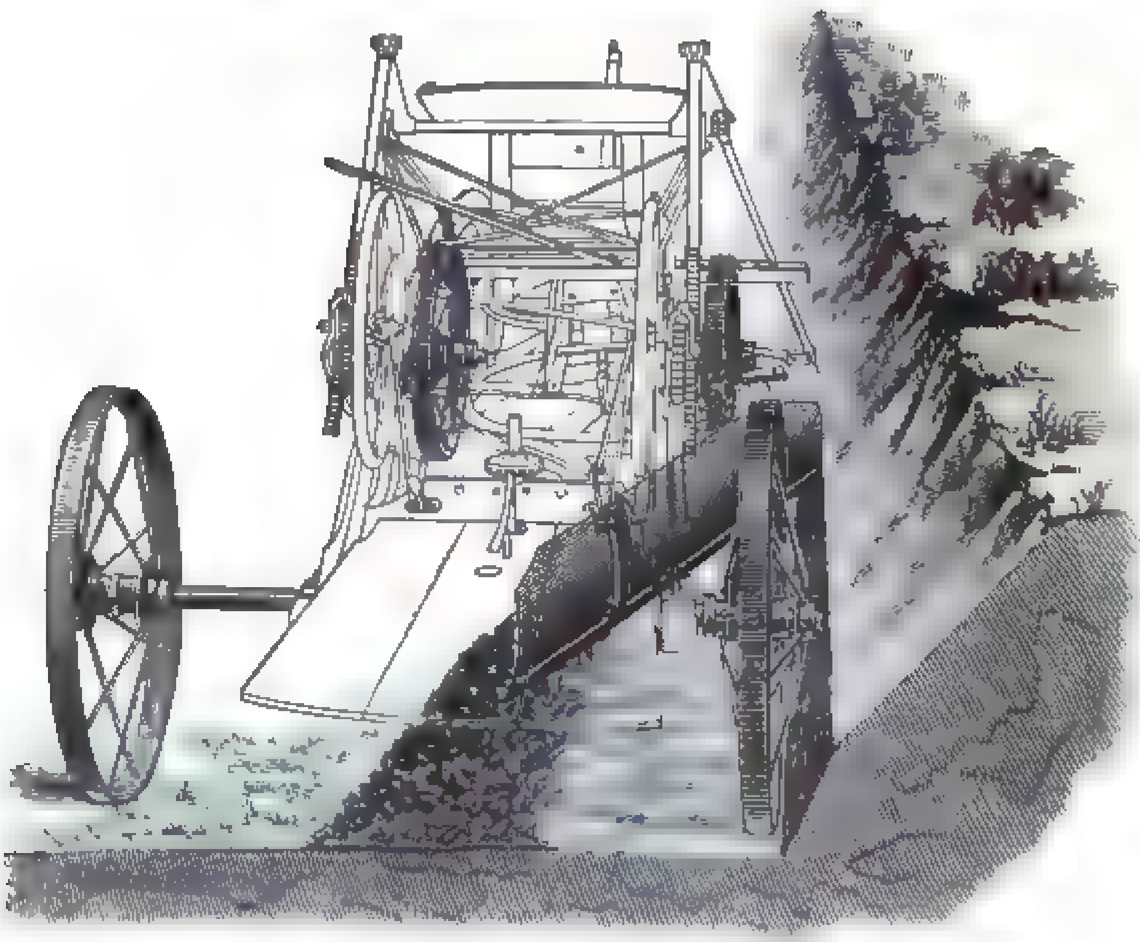


FIG. 30.—SCRAPING GRADER CUTTING AWAY OLD BANK.

If the ridge is formed, it can be flatted down by setting the blade square across the road and allowing the earth to flow under it; and

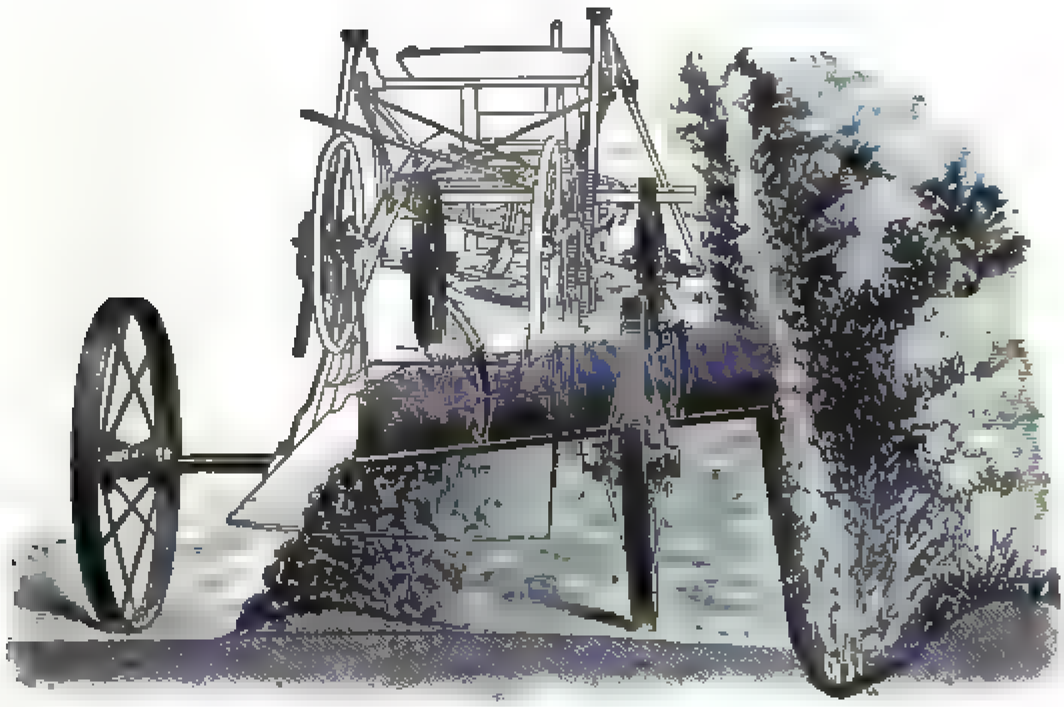


FIG. 31.—SCRAPING GRADER CUTTING SHOULDER FROM DEEP DITCH.

with most machines the center ridge can be leveled down by reversing the blade and using the back of it.

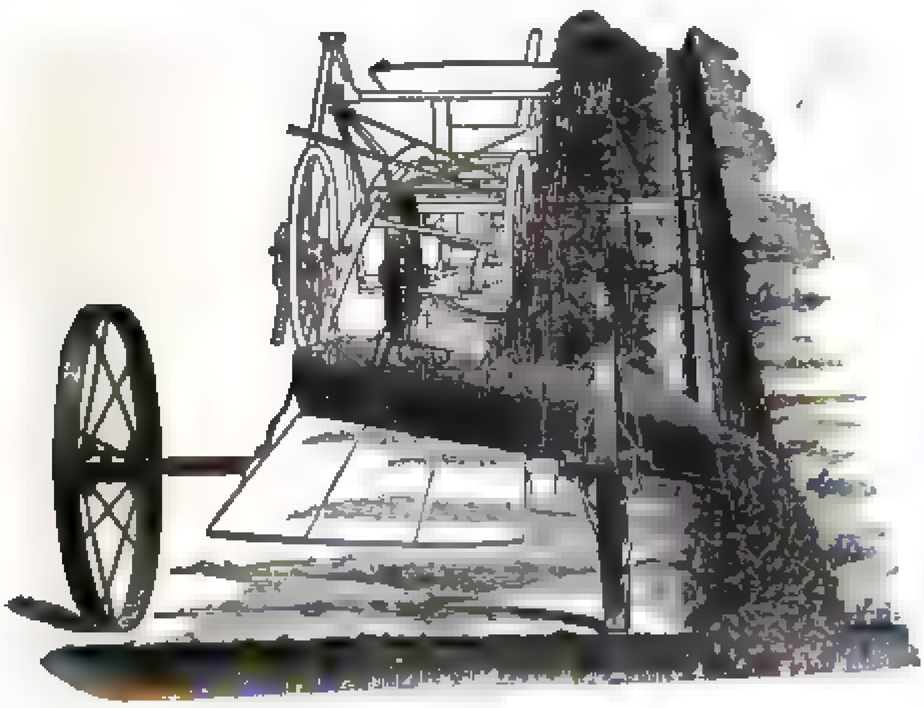


FIG. 32.—SCRAPING GRADER FILLING TILE DITCH.

If the ground where a road is to be constructed is covered with weeds and grass, it should be cleared by burning or by mowing and

raking. With sod ground the best road can be obtained by first cutting the sod as thin as possible and moving it to the center of the road, and then going back to the ditch and continuing the grading as described above. To cut a thin slice of sod, the scraper blade should be as sharp as possible. When the ground to be moved is covered with sod or weeds, some operators make the first cut on the

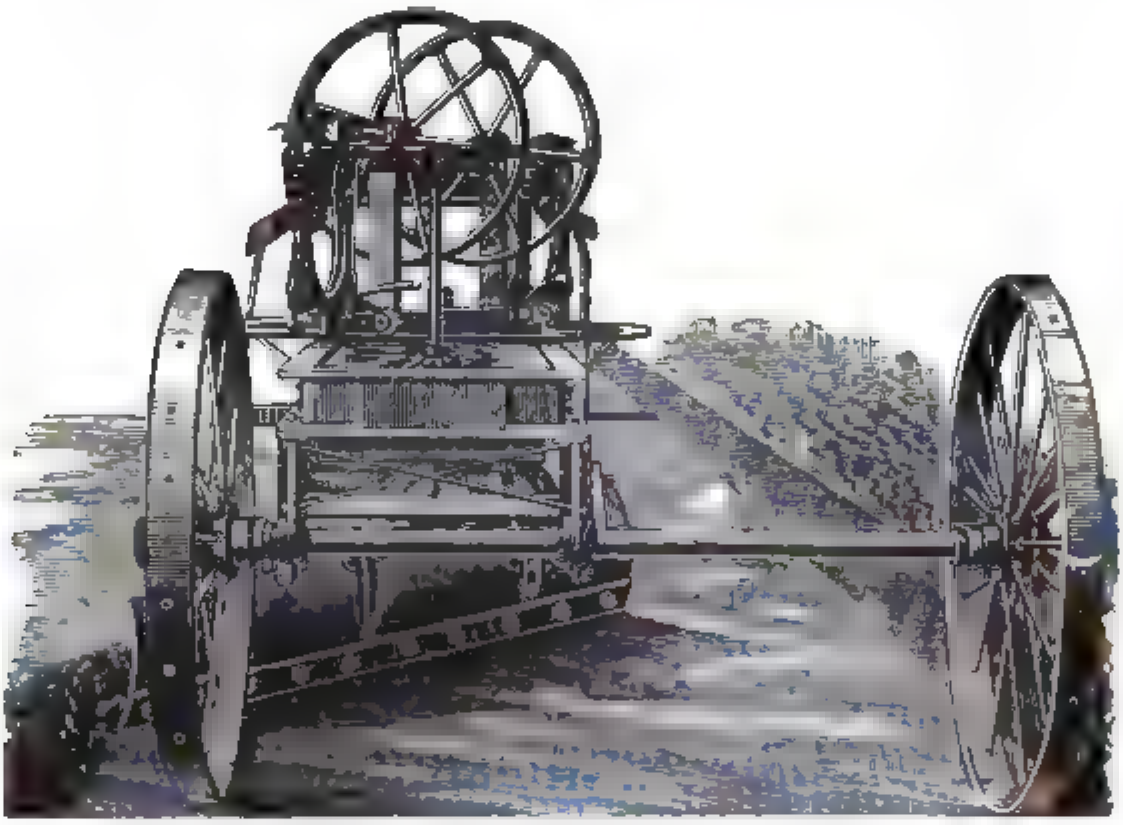


FIG. 33.—SCRAPING GRADER WITH ADJUSTABLE REAR AXLE.

inside of the ditch and at each successive round cut a little farther out, thus distributing the sod through the earth forming the roadway. This requires too much cutting with the unsharpened end of the blade, and is therefore not as good as the method described above.

146. It is best not to put more than 4 to 6 inches of loose earth into the road at one working, as that is all that can be thoroughly packed by traffic. If a greater amount is thrown up at one time, the bottom of the grade will remain soft and cause the road to cut into deep ruts as soon as the top has become thoroughly soaked by rain. As far as possible the grading should be done early in the summer, giving ample time for the loose earth to settle and pack before the fall rains. If worked in the fall, there should never be more than 4 inches of loose earth put upon the road at one working.

If the maximum amount of earth is to be placed upon the road at once, it is wise to roll each successive layer with as heavy a roller as is available or as the team can draw, as otherwise traffic will consolidate only the surface, and the bottom of the grade will long remain soft and spongy.

147. The scraping grader is usually drawn by four or six horses, depending upon their size, and the character and condition of the soil. One man can operate the machine, and one or two men are required to drive.

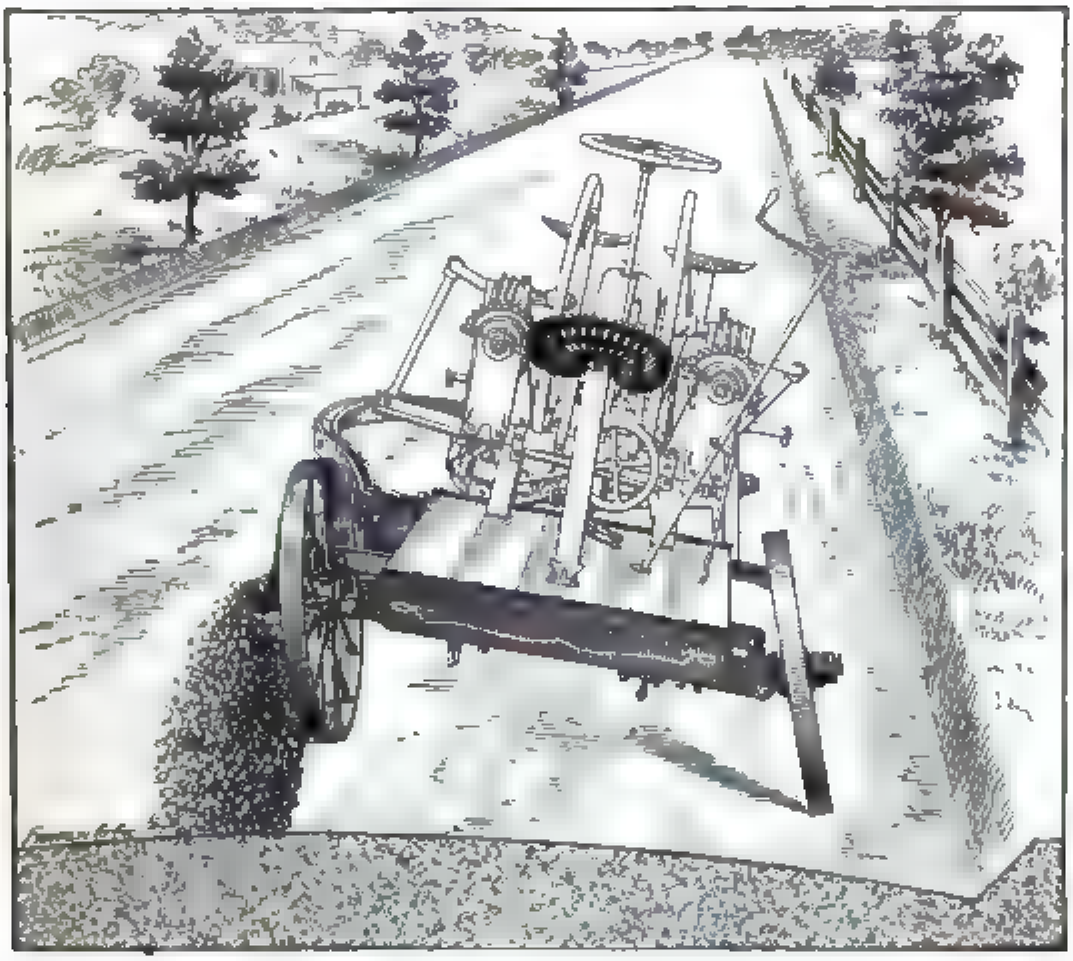


FIG. 34.—SCRAPING GRADER WITH INCLINED WHEELS.

A traction engine is sometimes used; and it is a better power, since it gives a steady draft and does not need to stop to rest. At certain seasons of the year, the traction engine is the cheaper power, and at other times horses are the cheaper, depending upon the requirements of horses for farm work and the demands for the traction engine in threshing and shelling.

148. The cost of building an ordinary prairie road with this machine is about $30 to $40 per mile, with a width of 30 or 35 feet

and a crown of 6 inches above the natural surface. The first is the cost when there is a stiff sod, and the second when there is none. A second 6 inches may be added for about $30 per mile.

If the ground is very dry and hard, another team and driver will be required, and the above prices may be nearly doubled.

149. Elevating Grader. The best known form of the elevating grader is shown in Fig. 35. It consists of a frame resting upon four

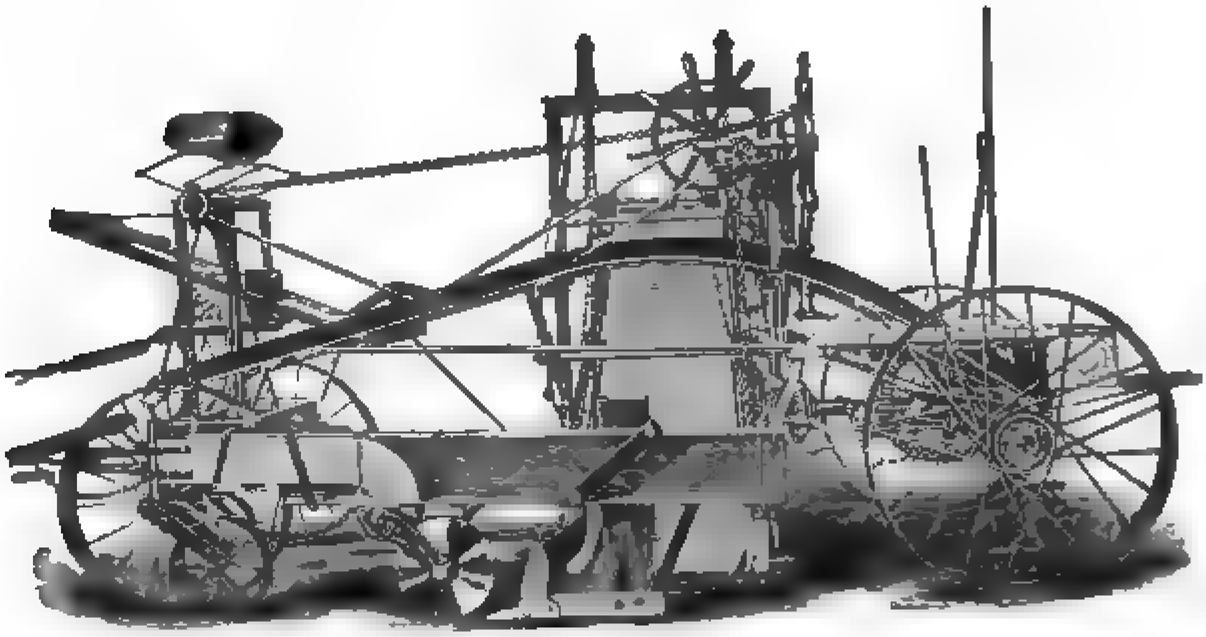


FIG. 35.—ELEVATING GRADER.

wheels, from which is suspended a plow and a frame carrying a wide traveling belt. The carrier is built in sections and its height is adjustable. The larger carrier will deliver earth 14, 17, 19, or 22 feet horizontally and 8 feet vertically from the plow; while the smaller size delivers 14 and 17 feet horizontally and 7 feet vertically. The smaller machine is designed for highway work. The plow loosens the soil and throws it upon the traveling inclined belt, which delivers it upon the embankment direct or into wagons.

This is an exceedingly effective machine for building open ditches, earth embankments, or filling wagons. By changing the length of the carrier and by properly distributing the earth, the machine will build either a broad low embankment from a narrow deep cutting, or a narrow high embankment from a broad shallow cutting; or the machine will excavate a deep narrow ditch with flat spoil banks, or a shallow ditch with narrow spoil banks. This machine is especially adapted to building earth roads in a prairie country, for which purpose it has been very largely used.

The large machine is usually propelled by twelve horses—eight in front and four behind,—and the smaller by eight in front. Often a traction engine is cheaper than horses. One man can operate the machine; and at least two men, and usually three, are required to drive the larger machine, but usually two drive the smaller one.

150. The factory price of the smaller machine is $1,200.

The large machine is guaranteed to place 1,000 cubic yards of earth in an embankment in 10 hours, or to load 600 cubic yards into wagons in the same time. The small machine will grade a quarter of a mile of ordinary prairie road per day, with a width of 25 to 30 feet and a crown of 12 inches at the center, at a cost of $11 to $14, or at the rate of, say, $45 to $60 per mile.

151. Recently there have appeared upon the market two forms of elevating graders consisting of a plow, carrier, and traction engine combined. So far as known these are still in the experimental stage.

152. *Operating the Elevating Grader.* To build a new road of the sections shown in Fig. 9 and 10, page 85, first mark by stakes a line 10 feet on each side of the center of the proposed road. With the machine arranged to carry 17 feet, drive along the left-hand row of stakes and back on the other side of the road in the same way. The streams of earth as delivered will overlap 5 or 6 feet. Start the machine on the second round with the right-hand forward wheel in the furrow of the previous round, and complete the round. A harrow should follow the machine to break up the sod and level the bank. Continue to make rounds until the ditches are as wide as desired.

Commence the second plowing by bringing the left-hand wheel of the machine to the left-hand edge of the first furrow cut, which brings the plow one furrow to the left of the point of commencing the first plowing, and keep this relative position while making this round. Make the second round with the right-hand forward wheel in the furrow of the previous round; and continue to make rounds until the outside of the ditch is reached again. For the best results a harrow and roller—the heavier the better—should follow the grader during the second and subsequent rounds. See Fig. 36, page 112.

When the second plowing has been completed, the grade will be

high and narrow; and therefore the carrier should be shortened to 14 feet. Then start the machine so that the plow will take a furrow from the center of the ditch, and continue the third plowing, as described above for the first and second, to the outside of the ditch. For the fourth plowing take a couple of furrows from the outside of the excavation to deepen the ditch.

The final result should be about as in Fig. 9, page 85. Most operators, however, leave a berm at the inside edge of the ditch (see Fig. 36), which is undesirable since it interferes with the operation of the scraping grader in maintaining the road.

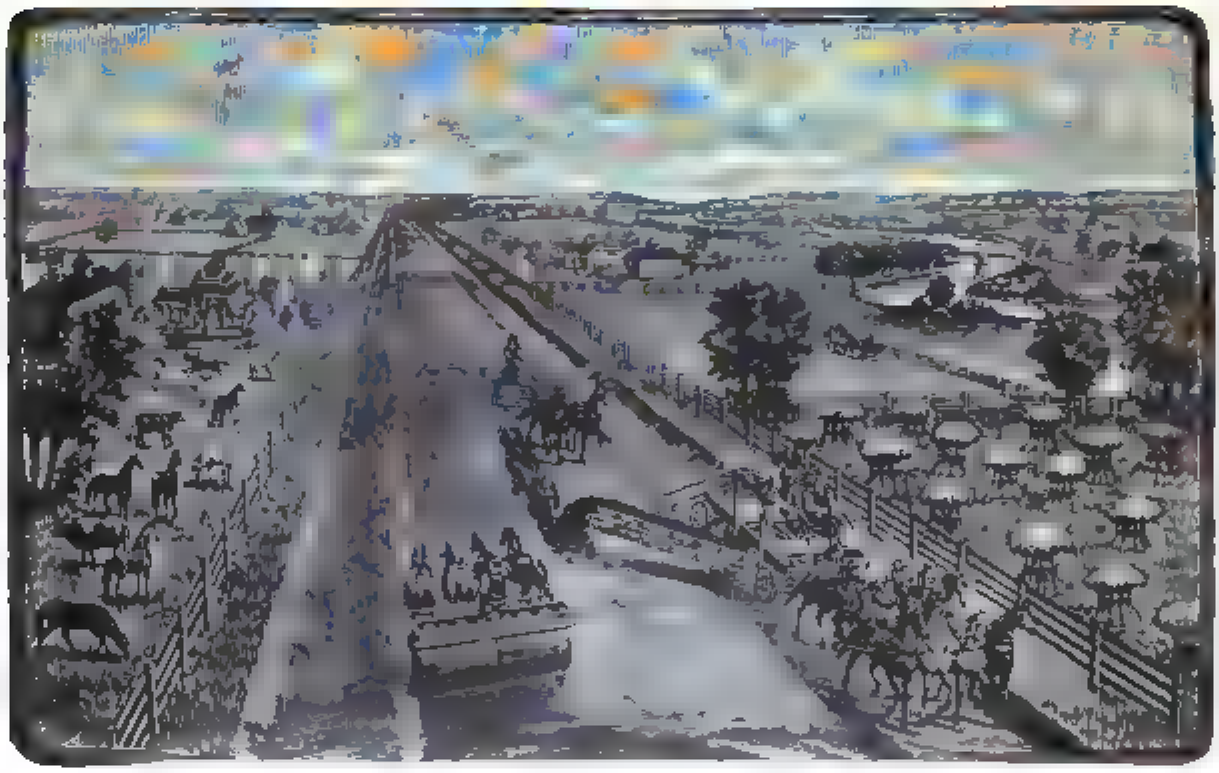


FIG. 36.—ELEVATING GRADER BUILDING EARTH ROAD.

153. For loading wagons, the carrier is arranged to deliver at 17 or 19 feet horizontally from the machine, the wagons are driven so that the earth falls from the carrier into the wagon, and both move at the same speed until the wagon is loaded; and then the grader slows down while the loaded wagon drives out and an empty one drives in. In a public test at Denver, Colorado, in 1890, 55 dump wagons were loaded in 22 minutes, or at the rate of 150 wagons per hour.* Common wagons with dump boards are not so easily loaded as the usual dump wagon, since they are narrower and longer. It

* Manufacturer's catalogue.

is customary to estimate three dump wagons for the first 100 feet of haul, and an additional wagon for each 100 feet thereafter.

154. COST OF EARTHWORK. Of necessity, general estimates of the cost of earthwork can not be very exact, since the cost will vary with the condition of the soil, the wages, the hours constituting a day's work, the relative amount paid for supervision, the effectiveness of the supervision, the facilities for preventing one part of the crew from interfering with the work of another, the proper adjustment of the number of shovelers per cart * or of scraper holders to scrapers, etc. The following data have been checked by engineers and contractors of wide experience and are believed to be reasonably reliable.

155. In the analysis of the cost of earthwork to follow, the price for a man will be assumed to be $1.50 per day of 10 hours, and that for a team and driver $3.50 per day. These are the usual wages paid by contractors, which are the prices to be considered here; for if the work is done under the labor-tax system ordinary estimates will not apply (see § 52–53), and if the farmer hires out to do the work of a teamster he usually demands the ordinary pay for that class of work. These are about the prices that have been established for a number of years in a number of states. Of course wages may be a little more when work is being rushed, or a little less when work is scarce.

156. Cost with Scraping Grader. In prairie soil, two men and four horses with a scraping grader can build a mile of road 36 feet wide from inside to inside of ditch with a crown of 6 inches at the center after being compacted, for $30 to $40, which is equivalent to $1\frac{3}{4}$ or $2\frac{1}{4}$ cents per cubic yard. The first is the cost when there is no sod, and the last when there is sod. The cost for a crown of 12 inches will be about $70 per mile, or $1\frac{3}{4}$ cents per cubic yard. The above prices do not include interest, or wear and tear of grader, which would be about $\frac{1}{4}$ cent per cubic yard. The total cost for

* For an interesting and instructive example of the way in which, by organization and management, the amount of earth shoveled into a cart was nearly double that ordinarily considered a fair average, and the total cost of moving the earth was only about half the usual amount—all without rushing,—see Annual Report of the Connecticut Civil Engineers and Surveyors for 1901, p. 148–56; or a full abstract of the same in *Engineering News* for Jan. 17, 1901, Vol. 45, p. 54–55.

scraping-grader work in prairie soil usually varies between $1\frac{3}{4}$ and $2\frac{1}{2}$ cents per cubic yard.

In hard soil requiring an extra team and hence another driver, add one half to the above prices.

157. Cost with Elevating Grader. The manufacturers guarantee that the elevating grader shown in Fig. 35, page 110, will deposit 1,000 cubic yards per day of 10 hours; and a number of testimonials are printed showing that 1,400 to 1,600 cubic yards is not unusual. This machine is guaranteed to load into wagons 600 yards per day, which is a cost of about 3 cents per cubic yard; and the manufacturers claim that it can be done for about half this sum.

A contractor in sandy prairie soil with fourteen horses and four men loaded 100 cubic yards per hour as a maximum and 60 as an average, the cost being as follows: 7 two-horse teams at $2.50 each *plus* 2 drivers at $2.00 each *plus* 1 operator at $2.00 and 1 at $2.50 = $29.50, which for an average of 600 cubic yards is per day equivalent to 4.9 cents per cubic yard. Ordinarily the cost of depositing earth direct in the embankment with an elevating grader varies from $6\frac{1}{2}$ cents to $8\frac{1}{2}$ cents, exclusive of interest, depreciation, and administration.

158. Cost with Drag-Scoop Scraper. Drag scrapers are admirably adapted for borrowing at the sides of embankments and for wasting from cuts or ditches, and also for opening the mouth of large cuts; but are not economical except for short distances. There is no danger of the scraper getting out of order until it is worn out and unfit for use, and the manner of using it is quickly learned by any one. Drag scrapers are made in three sizes having a capacity of 3, 5, and 7 cubic feet, respectively; but it must not be assumed that each scraper will carry to the embankment an amount equal to its rated capacity, since in the first place it is difficult to completely fill the scraper, and in the second place the scraper carries loose earth which will shrink about 25 per cent when compacted in the embankment. Unless the soil is very loose and easily loaded, it is not safe to assume that each trip of the scraper will make of completed embankment more than one half of its rated capacity. The larger size is most economical, but the relative advantage is not proportional to the size, since the larger size is not as easily handled nor as easy to fill. Scrapers should be used in gangs of not less

than six to decrease the cost of loosening, superintendence, spreading, etc.

159. *Cost of Loosening.* Sand or sandy loam can be scraped without plowing. In loam a two-horse team and plow will loosen 400 cubic yards per day, at a cost of $3.50 for team, plow, and driver, and $1.50 for the plow holder, making a total of $5.00, or 1¼ cents per cubic yard. Sometimes the driver can also hold the plow, in which case loosening will cost about 1 cent per cubic yard, since the team will not do quite as much work as when there is a plow holder and also a driver. If the ground is hard it will be necessary to add another team and also a man to "ride" the beam of the plow. If the ground is not very hard, this force will loosen 400 yards per day at a cost of 2.1 cents per cubic yard.

160. *Cost for 25-foot Haul.* The cost of building an embankment from a borrow pit at the side of the road will first be considered. For a 60-foot right of way and a light embankment, the length of haul or "lead" from center of gravity of the fill to the center of gravity of the cut will be about 25 feet. This distance will be a little more or a little less according to the height and width of the bank, and the width reserved for sidewalk; but slight difference in length of short hauls make comparatively little difference in the cost of moving the earth, because in the first place a considerable part of the cost of hauling is due to time consumed in turning and loading, and in the second place the cost of transportation is only about half the total cost of moving the earth.

On the road, an ordinary team will travel 220 feet per minute (2½ miles per hour), but in scraping considerable time is consumed in turning, waiting to load, etc., and besides, the distance traveled is more than that from the center of cut to the center of fill; therefore the ordinary speed of the team is no guide in this connnection. Experience shows that a team will use from a minute to a minute and a half in making a round trip at the above distance, or, say, 1¼ minutes per trip. A foot vertically is equivalent to 10 to 25 feet horizontally (see § 74), and in estimating the length of haul this fact must be taken into account.

The scraperful will make 3½ cubic feet of compacted embankment, or will require eight trips per cubic yard. Therefore a team will place a yard of earth in the fill every ten minutes, or 6 yards

per hour and 60 yards per day. In light loose earth, where it is easy fully to fill the scrapers, a team may make 70 yards; but if the ground is hard, or obstructed with roots and grass, 50 yards may be the maximum. Assuming a day's work to be 60 yards, the cost of hauling is $3.50÷60=5.83 cents per cubic yard.

One man will hold and fill the scraper for two teams at a cost of $1.50÷(2×60)=1.25 cents per yard. One man on the dump will ditribute and level the earth deposited by six teams, at a cost of $1.50÷(6×60)=0.4 cents per cubic yard. One foreman will be required at, say, $2.50 per day, or $2.50÷(6×60)=0.69 cents per cubic yard. For wear and tear of scraper we may allow 10 cents per day for each, or 60 cents for the lot; and for wear of plow and cost of sharpening, say, 30 cents, making a total of 90 cents or 0.25 cents per cubic yard. In very hard ground the above prices may be doubled.

The total cost of moving earth 25 feet will then be as in Table 14, page 118.

161. *Cost for 50-foot Haul.* We will next consider the cost for a 50-foot haul. At this distance a scraper holder can fill for three teams. Each team can put in about 50 cubic yards per day. The other items will be substantially as for a 25-foot haul, and the total cost will be as in Table 14.

162. *Cost for 100-foot Haul.* Each team will make a trip in about 2½ minutes, and will put in 40 cubic yards per day. The total cost will be as in Table 14.

163. *Cost for 200-foot Haul.* At this distance a scraper holder can fill for four teams. Each team will make the trip in about 3½ minutes, and put in about 35 cubic yards per day. The total cost will then be as in Table 14.

164. *Cost for Hard Ground.* If the ground is so difficult to plow as to require a second team and a man to ride the beam, add 1 or 1½ cents to the values in Table 14 for the extra cost of loosening; and add, say, one fifth to the cost of hauling to allow for the fact that in hard ground the scrapers are not as well filled as in loose light soil. Also add one half to the above estimated cost of wear and tear. The results for hard ground are then as in Table 14.

165. Cost with Wheel Scrapers. Wheel scrapers are excellent for hauling earth distances up to 600 or 700 feet. They are made

in three sizes, No. 1, 2, and 3, having a capacity of 9, 12, and 15 cubic feet respectively. With No. 1 the team fills its own scraper, while with No. 3 an extra team, a snatch team, is required to fill the scrapers reasonably full, and unless the ground is very loose and light an extra team is required to fill No. 2. Most contractors use either No. 1 with a single team or No. 3 with a snatch team. It usually takes about five loads with No. 1 to make a cubic yard in place; four, with No. 2; and three, with No. 3.

166. *Cost for 100-foot Haul.* It is assumed that the scrapers will be worked in a gang of six, which will require one foreman, one plow, three scraper holders, and one man on the dump. The expense for these items will be the same as for the drag scrapers, and are so entered in Table 15, page 119. At this distance a trip will occupy 2½ minutes, and a yard will be deposited every 10 minutes, or 60 yards per day, at a total cost of $3.50 or 5.83 cents per cubic yard for hauling.

The wear and tear is computed on the assumption that a scraper will last for 200 days' continuous work, making a cost for depreciation and repairs of, say, 20 cents per day per scraper. The wear and tear on the plow will be estimated at 30 cents per day. The total cost will then be as in Table 15.

167. Notice that the cost for 100 feet with the wheel scraper is 9.99 cents per cubic yard, while with the drag scraper for the same distance it is 12.67 cents. The difference is in the cost of hauling, and is due to the difference in the capacity of the two scrapers.

168. *Cost for 200-foot Haul.* A trip will be made in about 4 minutes, and each scraper will put in 50 cubic yards per day. The three scraper holders can fill an additional scraper, making nine in all. The cost will then be as in Table 15.

169. *Cost for 300-foot Haul.* In this case another scraper can be added, making four teams to each scraper holder. A trip can be made in about 5½ minutes, and each team will move 45 yards per day. The cost will be as stated in Table 15.

170. *Cost for 400-foot Haul.* It is difficult to determine the most economic distance for each size of scraper, since the several sizes are seldom available for making the test. However, at 300 feet, the cost with a No. 2 scraper is about the same as with a No. 1 at 200 feet; and at 400 feet the cost with a No. 2 is about the

TABLE 14.

COST OF MOVING EARTH WITH DRAG SCOOP-SCRAPER.

Cents per Cubic Yard.

Ref. No.	Items.	25-ft. Haul.		50-ft. Haul.		100-ft. Haul.		200-ft. Haul.	
		Loose Earth.	Hard Ground.	Loose Earth.	Hard Ground.	Loose Earth.	Hard Ground.	Loose Earth.	Hard Ground.
1	Loosening	1.25	2.50	1.25	2.50	1.25	2.50	1.25	2.50
2	Filling scrapers	1.25	1.50	1.00	1.50	1.00	1.25	1.00	1.00
3	Hauling	5.83	6.50	7.00	7.70	8.75	9.62	10.00	11.00
4	Leveling	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
5	Superintendence	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69
6	Wear and tear	0.25	0.38	0.33	0.50	0.42	0.63	0.53	0.80
7	Water boy	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
8	Total cost	9.83	12.13	10.83	12.95	12.67	15.25	14.03	16.55

TABLE 15.

COST OF MOVING EARTH WITH WHEEL SCRAPERS.

Cents per Cubic Yard.

Ref. No.	Items.	Length of Haul in Feet.							
		Using Scraper No. 1.			Using Scraper No. 3.				
		100	200	300	400	500	600	700	800
1	Loosening	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
2	Filling scrapers	1.25	1.00	1.00	1.80	1.80	1.80	1.80	1.80
3	Hauling	5.83	7.00	8.00	7.77	8.77	9.77	10.77	12.77
4	Leveling	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
5	Superintendence	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69
6	Wear and tear	0.41	0.58	0.75	0.53	0.64	0.75	0.86	0.97
7	Water boy	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
8	Total cost	9.99	11.08	12.25	12.60	13.71	14.82	15.93	18.04

same as with a No. 1 at 300 feet. But at 400 feet a No. 3 is more economical than a No. 2.

A snatch team is required in filling No. 3 scrapers. The extra force acquired by using the extra team completely fills the scraper, and also packs the load so that it is less liable to spill than when loaded by a single team. For this distance it is most economical to work the scrapers in a gang of eight; and two men will be required to hold the scrapers while being filled. Each team will put into place 45 cubic yards, or 360 for the gang. The total cost will be as shown in Table 15.

171. *Cost for Other Distances.* For each additional 100 feet of lead, add 1 cent per cubic yard to the cost of haul; and the total cost will be approximately as shown in Table 15.

When the amount of earth to be moved is considerable and the length of haul is great, something must be allowed for keeping in repair the road over which the earth is transported. A wheel scraper is prone to wear a series of humps and hollows along the road it traverses, and these must be kept in subjection, if the work is to be done at reasonable cost. The proper allowance will vary greatly with the soil, the weather, etc. Trautwine recommends 0.1 cent per cubic yard per 100 feet for this expense.

172. It is difficult to determine at what distance wagons should supersede wheel scrapers; but usually the economic limit for wheel scrapers is 600 to 800 feet, and it is seldom wise to use scrapers beyond 800 feet—unless they are at hand and wagons are not.

173. Cost with Wagons. It will be assumed that the wagons are used in gangs of nine, and haul 700 to 800 feet. If the roads are level and fairly smooth, a load will make about 1¼ cubic yards in place, and with ordinary roads 1 yard will make a load; but if the roads are soft and steep ¾ of a yard may make a load. The amount a team can deliver will vary greatly with the time consumed in waiting to load and in loading. With short wagon-hauls and well-organized work, half of the time is thus consumed, and many times much more is thus consumed. The time of the wagon while loading should be considered as a part of the cost of loading, and this will be discussed more fully in the next paragraph. For the above distance, the round trip will consume 15 minutes; and assuming a

yard as a load, each wagon will deliver 50 cubic yards per day, at a cost of 7.00 cents per cubic yard for hauling.

There is very great variation in the amount of earth a shoveler will load in a day. In well managed work, the shovelers are not actually engaged in loading much more than half of the time; while under poor management, they do not really work half of the time. With short intervals of rest equal to the working time, a man should load, in a day of 10 hours, 20 cubic yards of light sandy soil, 17 yards of loam, and 15 of heavy soil—provided all are loosened by plowing or picking. Usually five or seven men are set to load a wagon—two or three on each side and one at the rear. Seven men will load a wagon with loam in 5 minutes, 8 minutes will be consumed in traveling to and from the dump, 1 minute in dumping, and 1 minute in getting into and out of the cut—making in all 15 minutes for a round trip; and therefore the cost for wagon and team is 8.75 cents per cubic yard, as above. In this case the team works only about half the time. If only five men are engaged in loading a wagon, 7 minutes will be consumed in loading, and the time for a round trip will be 17 minutes, and each wagon will deliver only 35 cubic yards, making the cost 10 cents per cubic yard. In this case, the team really works less than half the time. If the men shovel only 12 to 15 cubic yards each, as is very common, the loss by the wagon's waiting for a load is considerably more than the above. The proper number of men to be set to loading a wagon depends upon the relative wages of shoveler and wagon, upon the length of the haul, and upon the quantity loaded per day per man.* Usually seven shovelers are employed to each wagon, but this number is not enough to secure the greatest economy. In the following estimates it will be assumed that nine shovelers are employed to each wagon. At the above distance, nine shovelers, each loading 17 yards per day, will be required to keep three wagons going, each of which deposits 45 cubic yards per day. The cost of loading will then be 8.8 cents per cubic yard.

The cost of leveling the dump is small, if dump wagons are used

* For the details of a very ingenious and effective adjustment of these relations, see an article by G. A. Parker, in Proceedings of Connecticut Civil Engineers and Surveyors, 1901, p. 148–56; or a full abstract of the same in *Engineering News*, Jan. 7, 1901, Vol. 45, p. 54–55.

and the earth is dumped over the end of the embankment or wasted; and it may be taken the same as for scrapers, i. e., at 0.40 cents per cubic yard. But dump wagons are so heavy and expensive that they are seldom used; and if ordinary wagons with dump boards are employed, the expense for labor on the dump will be about three times as great as above, or, say, 1.20 cents per cubic yard.

The driver furnishes his own wagon, and hence no account is taken of the wear and tear of it. There should be a small allowance made for the wear and care of shovels, say, 0.1 cent per cubic yard.

The total cost of moving earth 700 to 800 feet with wagons, then, is as follows:

1. Loosening	1.25 cts. per cu. yd
2. Shoveling	8.80 " " " "
3. Hauling 700 to 800 feet	7.00 " " " "
4. Helper on dump	1.20 " " " "
5. Superintendence	0.69 " " " "
6. Depreciation of shovels	0.10 " " " "
7. Water boy	0.16 " " " "
Total cost	18.20 " " " "

174. For longer distances add 1 cent per cubic yard for each 100 feet of distance—the usual charge for over-haul.

175. Other Methods. When the haul is more than 600 or 800 feet, and when the amount of work to be done is sufficient to justify the initial expense, it is more economical to use portable track and small dump cars than to use wagons. However, such conditions seldom occur in wagon-road construction.

176. Finishing the Slopes. In addition to the elements of cost discussed above, there is always some expense in leveling off the bottom of the cut, in digging ditches, in trimming up the slopes of embankments and excavations, and in cutting a catch-water at the top of the slope in excavation. The cost of these items will vary greatly with the degree of finish required and also with the depth of the cut or the fill; and it may amount to 0.25 or 0.50 of a cent per cubic yard. If the bottom of the cut can be leveled off with the scraping grader, and if the ditch also can be made with this machine, the cost of this item will be considerably reduced.

177. Profit to Contractor. The proper allowance under this head will vary according to the magnitude of the work, the risks involved, etc.; but will usually be 5 to 15 per cent. Out of this the contractor must pay the expense of assembling the plant, the cost of tool house, the wear and tear on small tools, interest on investment, etc.

178. BRIDGES. This subject will not be considered here, since the space available is not sufficient, and since there are a number of elaborate treatises on bridges. None of these, however, gives an adequate treatment of the very small highway bridge or fairly represents current practice for moderate spans.

179. WATERWAYS. The determination of the amount of waterway required for any particular bridge or culvert is a matter of importance. Although the problem does not admit of an exact mathematical solution, it requires intelligent treatment. For a discussion of this subject, see pages 391–96 of the author's Masonry Construction.*

180. CULVERTS. For a discussion of the cost and method of construction of culverts—wood box, vitrified pipe, cast-iron pipe, stone box, and masonry-arch culverts,—see the author's Masonry Construction, pages 396–439.*

One common defect of earth roads is that culverts are made too short, which concentrates the traffic upon the portion of the road usually least able to bear it. A short culvert may be permissible when the cost per unit of length is great, but the defect is common where this cost is quite small.

181. RETAINING WALLS. Retaining walls are masonry structures employed to support the sides of roads on hill-sides or in places where land for the ordinary earth slopes is not readily obtainable. For a discussion of retaining walls, see the author's Masonry Construction, pages 338–52.*

182. GUARD RAILS. Roads on steep hill-sides or on high embankments, and particularly on sharp curves in mountain roads, should be protected to insure vehicles against the possibility of falling down the slope. In Europe such protection is usually afforded by a stone wall, or by stone posts set at frequent intervals.

* A Treatise on Masonry Construction, by Ira O. Baker, 556 + 56 pp., 6 × 9 inches, cloth, 9th edition. John Wiley & Sons, New York. Price $5.00.

In this country the usual protection is by means of wood posts and wood guard rails. On the state-aid roads in Massachusetts, the specifications for the guard rails are as follows: "Posts of cedar, or other wood which endures well in the soil, are set at intervals of 8 feet, and 1 foot in from the edge of the embankment. These posts are planted to the depth of 3 feet, and project for 3 feet 6 inches above the ground. The top of this post is transversely notched, so as to receive one half of a rail four inches square. Half-way down, the post is notched to receive another rail two by six inches in size. These rails, preferably of planed spruce wood, are spiked to the posts. To insure the better preservation of the wood and its visibility in the night-time, it is painted with two coats of oil paint of some light color." For a diagram of this guard rail, see Fig. 54, page 210.

The Massachusetts Highway Commission wherever practicable widens the base of the embankment until a slope of 1 to 4 is obtained, and then dispenses with the guard rail. This plan is believed to be more economical, and to give a better appearance.

183. GUIDE POSTS. Some states, by statute, require guide posts at all intersections, and their value to the occasional traveler is sufficient to justify the expense. The guide post may be a plain post, supporting near its top a board upon which is the name of the place reached by the intersecting road, with figures showing the distance, and a ☞ to show the direction.

184. ARTISTIC TREATMENT. Engineers are accustomed to study chiefly or only the economic side of construction, and are therefore likely to neglect the artistic treatment of the highway. In the attempt to beautify the roadside, it may be necessary to sacrifice a little of utility to secure a pleasing effect. Masses of foliage and shade add beauty to the roadside, but tend to keep the traveled way damp—usually the bane of good earth roads. Trees are a necessary adjunct to a beautiful highway, but are anything but a benefit to the traveled way. If beauty is desired at the expense of utility, highways can scarcely be too much shaded by over-arching boughs. However, a happy medium will suffice in most places.

The varieties of trees suitable for the ornamentation of highways are almost infinite. The elm, with its graceful arching branches and delicate lace-like foliage, is not surpassed; and the hard maple

and the oaks are very handsome for this purpose. The walnut, the butternut, the hickory, the beech, the poplar, and the pine, ranging from the most delicate to the most somber and rugged, are all more or less adapted to particular requirements and circumstances. Trees such as willow, the roots of which spread extensively or seek water, should not be permitted to grow near tile drains, as the small roots frequently entirely obstruct the tile. Trees should not be planted close to the traveled way, but near the edge of the right of way, or if possible on the private property bordering the road.

185. The roadside fences are usually the property of the adjoining land owner, and may mar or beautify the landscape. The hedge rows of England and the stone fences of New England are all that can be desired for appearance, but in localities where there is much snow they catch the drifting snow and so obstruct the highway. The only thing favorable to the appearance of the common wire fence is that it is inconspicuous.

ART. 2. MAINTENANCE.

186. Proper maintenance is as important as good construction. A distinction should be made between maintenance and repairing. The former keeps the road always in good condition; the latter makes it so only occasionally. If the road is not properly maintained, it deteriorates in a geometrical ratio. A small depression fills with water and soon becomes a mud hole which traffic makes deeper and deeper; or an obstructed side ditch forces the water to run down the center of the road, and gullies out the surface. A defect which could be remedied in the beginning with a shovelful of earth or a minute's time, if neglected may require a wagon load of earth or an hour's time, besides being in the meantime an annoyance or a damage to traffic. The better the state in which a road is kept, the less are the injuries to it by ordinary traffic and the weather.

187. DESTRUCTIVE AGENTS. Water. Water is the natural enemy of good earth roads. The chief object of maintenance should be to keep the surface smooth and properly crowned so that rain will be shed into the side ditches. These should be kept open so that the water may be carried entirely away from the road. This subject is fully considered in § 194.

188. Narrow Tires. It is desirable that a wagon in passing over the road should help to make or preserve it, and not to destroy it; and therefore as far as the road is concerned, within reasonable limits, the broader the tire the better.

"The matter of width of tires has been a subject of much remark. There has, indeed, been no end of idle talk concerning this matter, much of it directed to the point that our American wagon-builders have shown a lack of judgment in building with narrow tires, while they should provide their vehicles with broad treads such as are in use in Europe. The fact is that in this, as in many other ways in which our people have departed from ancient and old-world customs, they have been led by wisdom and not by folly. This will on a little consideration be made evident. Where there is no definite pavement, as in ninety-nine hundredths of the mileage of American roads, the wheels have in muddy weather to descend into the earth until they find a firm foundation on which to rest. In so doing they have to cleave sticky mud which often has a depth of a foot or more. If these wheels were broad-tired, the spokes would also have to be thick and the felloes wide, so that the aggregate holding power of the mud upon the vehicle would be perhaps twice what it is at present. It is useless to talk about the advantages of a broader tread to the wheels of our wagons until we have a thoroughly good system of roads which they are intended to traverse. Any laws looking to this end would be disobeyed because of private needs so general that they would amount to a public necessity. When the roads of a district are made good only as to the main lines of communication, the side roads and the farms still demand the peculiar advantages afforded by the narrow tire." *

Tables 4 and 5, pages 24 and 25, show that under some conditions the narrower tire requires less tractive power than the wider tire, which supports the claim in the above quotation.

Although there is not much difference between the tractive power of broad and narrow tires, the latter are much more destructive on any road, particularly on an earth one; but in deciding upon the proper width of tire, there are other factors besides the road that

* American Highways, N. S. Shaler, Dean of Lawrence Scientific School, Harvard University, and formerly President of the Massachusetts Highway Commission, p. 163-4.

must be considered. If wagons were employed only upon the public highway, it might be wise to use wide tires and sacrifice some tractive power for the benefit of the roads. Other things being equal, a wagon with broad tires is not so easily managed as one with narrow tires. To be equally easy to turn, the broad-tired wagon should have the narrower bed, or the longer front axle, or the smaller front wheel. In Europe it is customary to adopt the smaller front wheel, which is very destructive of the broken-stone roads so common in that country. Increasing the length of axle interferes with getting the wagon up to cribs, warehouses, etc., and increases the difficulty in going through gates, passing buildings, and the like, and hence it is not clear that laws should be passed regulating the width of tires, many claims to the contrary notwithstanding.

"The best argument against the enactment of laws concerning broad tires is found in the fact that the numerous and long-enforced English statutes on this matter have of late years been abrogated, a century of experience having shown that they are difficult to administer and generally disadvantageous." * The Massachusetts Highway Commission, after an elaborate discussion of the subject,† says: "It is a matter of doubtful expediency to endeavor, in the present state of our highways, by general legislation to control the width of tires or the diameter of wheels."

It is probably best to leave the matter to private individuals and the enterprise of manufacturers. The matter should at least be left to local authorities to pass regulations which shall be suited to their particular conditions. Several states and cities have laws regulating the width of tires, but it does not appear that broad tires are any more common there than in localities where no such laws exist.

189. Many European countries have laws regulating the width of tires. In England for 100 years the law required 1 inch of tire for each 500 pounds of load, but all laws regulating the width of tires have been repealed. In France the tires of market carts vary from 3 to 10 inches in width, being generally from 4 to 6 inches,

* Shaler's American Highways, p. 165.

† Report of the Massachusetts Highway Commission for 1893, p. 56–62.

with the rear axle about 14 inches longer than the forward one. In Bavaria the legal width is as follows:

Minimum width of tires of 2-wheeled carts, with	2 horses,	4.13	inches
" " " " " 2-wheeled " "	4 "	6.18	"
" " " " " 4-wheeled wagons, "	2 "	2.60	"
" " " " " 4-wheeled " "	3 or 4 horses,	4.13	"
" " " " " 4-wheeled " "	5 to 8 "	6.18	"

In this country a number of the states have statutes concerning the width of tires, many of which take the form of a rebate, either cash or part of the road tax, to those using tires of a prescribed width. The following is the legal width in Ohio:

Minimum width of tire for load of	2,500 to 3,500 pounds	 3	inches
" " " " " " "	3,500 " 4,000 "	.... 3½	"
" " " " " " "	4,000 " 6,000 "	 4	"
" " " " " " "	6,000 " 8,000 "	 5	"
" " " " " " "	8,000 or more "	 6	"

According to wagon manufacturers about 60 per cent of the wagons used on country roads have tires 1½ to 1¾ inches wide, those of the remaining 40 per cent being 2 to 4 inches. The broad tire is of comparatively recent introduction on rural roads in this country.

190. In some respects the injury by narrow tires is greater on broken-stone roads than on earth roads, since the damage can be more readily repaired in the latter than in the former; but even on a broken-stone road, there is a limit beyond which it is not wise to increase the width of the tire. The crown of the road is such that the point of contact with the road is at one edge of the tire, and it is generally conceded that no material advantage is gained in making the tire more than 4 or 5 inches wide.

191. Equal Axles. Since the hind wheel follows in the track of the fore wheel, it increases the depth of the rut, and consequently increases the destructive effect of the wagon upon the road. The remedy would be to make the lengths of the two axles unequal, but this would make the wagon more difficult to manage and would also increase the tractive resistance. The advantage of not permitting one wheel to exactly follow another, is shown by the fact that there are no ruts at a corner or a sharp turn in the road; but it is not practicable to secure this advantage generally, either by

making the two axles of unequal length or by preventing a wagon from traveling in the ruts already made.

192. Small Wheels. The smaller the wagon wheels the greater the destructive effect upon the road, and also the greater the tractive power required; but for ease of loading and convenience of management, low wheels are better than high ones. It is probably wise to permit those who use the wagons and the roads, and pay for both—usually the farmers—to determine the most economic diameter of wheels.

The wagons in ordinary use on country roads have three sizes of wheels, as follows, for the front and the rear wheels respectively:

3 feet 2 inches and 3 feet 8 inches
3 " 6 " and 3 " 10 "
3 " 6 " and 4 " 6 "

According to wagon manufacturers about 80 per cent of the wagons on the country roads have the last-named size of wheels.

193. Horse not Hitched Before Wheel. On broken-stone roads, the horses' feet loosen fragments of stone, which tends to destroy the surface; and if the horses were hitched directly in front of the wheels, the stones loosened by the horses' feet would be rolled down by the wheels of the wagon. This is a matter of some moment with broken-stone roads, but is hardly practicable with earth roads. However, some teamsters hitch their horses in front of the wheel, to enable their horses and wheels to run in the beaten track made by the feet of preceding horses not hitched in front of the wheel.

194. CARE OF THE SURFACE. The most important work in maintaining an earth road is to keep the surface smooth so that the rain water will flow quickly into the side ditches. If the surface of the roadway is properly formed and kept smooth, the water will be shed into the side ditches and do comparatively little harm; but if it remains upon the surface, it will be absorbed and convert the road into mud. If all ruts, depressions, and mud holes are not filled as soon as they appear, they will retain the water upon the surface, to be removed only by gradually soaking into the road-bed and by slowly evaporating; and each passing wheel or hoof will help to destroy the road.

There are several machines or devices which are very effective

in filling ruts and depressions, and in keeping the surface smooth. Different tools are best under different conditions. These tools and the method of using them will be considered briefly.

195. Harrow. In the winter there frequently come times when the road is full of holes and ruts, while the surface soil is dry and mellow. This condition occurs most frequently when the ground below the surface is frozen. If at this time a harrow is run over the road, it will fill up the ruts and holes and leave the surface comparatively smooth. This improves the road for present travel, and gives a smooth surface which will greatly decrease the deterioration of the road by subsequent rains. The ordinary adjustable farm harrow should be used, and the teeth should be set to slope well back. The labor required is not great, since a 12-foot harrow can be used, and then a single round is sufficient.

Often there are only a few hours in the middle of the day when the frost is out of the ground sufficiently to permit this work to be done, and therefore it is best for each farmer to harrow the road adjoining his own land (see paragraph 3 of § 46). The work comes at a season of year when the farmer's time is usually not very valuable, and hence the expense is small. This method of treating earth roads has proved very beneficial both in securing good roads and in preserving them.

In the summer, when the roads get roughed up, they can be materially improved at small expense by running over them with a harrow having the teeth down quite flat. If the roads are a little muddy, this treatment will make them dry faster and also make them much more pleasant to use after they have dried.

196. Railroad Rail. In the early spring, just after the frost goes out of the ground, earth roads are usually full of deep ruts. The harrow is not suitable for the work now required. The object is simply to cut off the ridges and fill up the ruts, and thus "break the way" for travel. It is well to break the road early in the season, both to accommodate immediate travel and to hasten the coming of a better condition of the road. It is much more economical to make the road smooth with a machine than to wear it down by travel.

There are many road machines on the market, all of which are most excellent for certain kinds of work to be referred to later, but

most of which are too heavy for the conditions just described. Most of the machines are mounted upon four wheels, and of themselves are a considerable load over roads which are only a succession of ridges, ruts, and mud holes; and are heavier and more cumbersome than is necessary for the work now under consideration.

197. A railroad rail 14 to 16 feet long drawn by two two-horse teams has been used with great success in breaking down the ridges and filling up the ruts. The team is hitched to an eye fastened through the web 2 or 3 feet from the end of the rail. The edge of the base of the rail serves as a cutting edge. A 7-inch steel I-beam is equally good.

When the ground is mellow and loose after freezing and thawing, the steel rail will smooth the road nearly as satisfactorily as the scraping grader (§ 142) and much more rapidly, since it cuts a wider swath and since the draft is so light that the teams walk right along. One round trip is usually sufficient for any road. The time when the work is most advantageously done is comparatively limited, and therefore one rail should not be expected to cover too much road. The cost is so small that one can be provided for each few miles of road,—the number depending upon the nature of the soil and the climate. If roads are treated in this way, they will not get so rough; and hence will require less work later with the heavy road machine.

198. Light Scrapers. A heavy stick of timber faced on one side with a steel plate, and hitched behind a wagon or drawn by a team direct, is very effective in smoothing the way for travel. To the top face of the timber should be fastened a frame by which to hitch the leveler to the wagon or team. This frame should be in the form of a capital A with one leg a little shorter than the other, to cause the cutting edge to stand obliquely to the line of draft.

Fig. 37, page 132, shows a slightly more elaborate form of road leveler. The blade is usually about $\frac{1}{4}$ inch thick, 4 inches wide, and 72 inches long. The timber is 6×12 inches square by 6 feet long. This form costs \$10 to \$12.

Fig. 38, page 132, shows a still more elaborate form of road leveler. The blade is all steel, and may be tilted forward or backward. The catalogue price of this machine is \$50.

199. The advantage of these scrapers or road levelers is that

they are cheap, and are easily handled. They do a little better work than the railroad rail, but their first cost and cost of operation

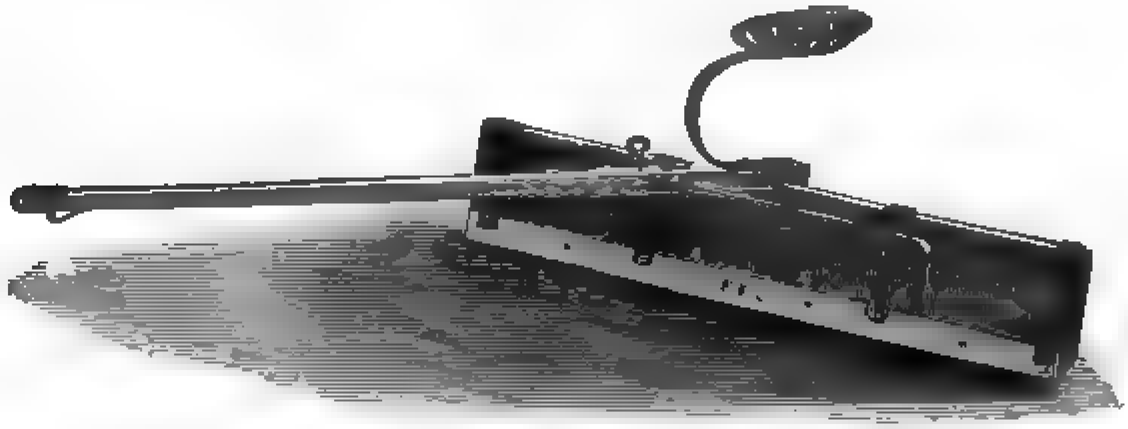


FIG. 37.—SIMPLE ROAD LEVELER.

FIG. 38.—DETROIT ROAD LEVELER.

is considerably more; and they are not as effective as the four-wheel scraping grader, but their first cost is much less and they are easier handled. They are not effective when the road is very rough or very hard.

200. Two-wheel Scrapers. There are several two-wheel road scrapers upon the market, of which Fig. 39, page 133, is the most elaborate. The blade of this machine is adjustable in both the horizontal and the vertical plane, and can be raised and lowered. The wheels can be inclined to neutralize the resistance of the furrow to being moved laterally; in other words, the oblique wheels prevent the whole machine from sliding sidewise.

The other two-wheel machines consist virtually of the blade of the scraping grader (§ 142) carried on a pair of high wheels, and are the results of an attempt to supply a cheaper machine than the four-wheel scraping grader.

201. No two-wheel scraper can do as good work as the four-wheel

machine shown in Fig. 24, 25, and 34, pages 102 and 109, since the long frame with four points of support gives a more uniform

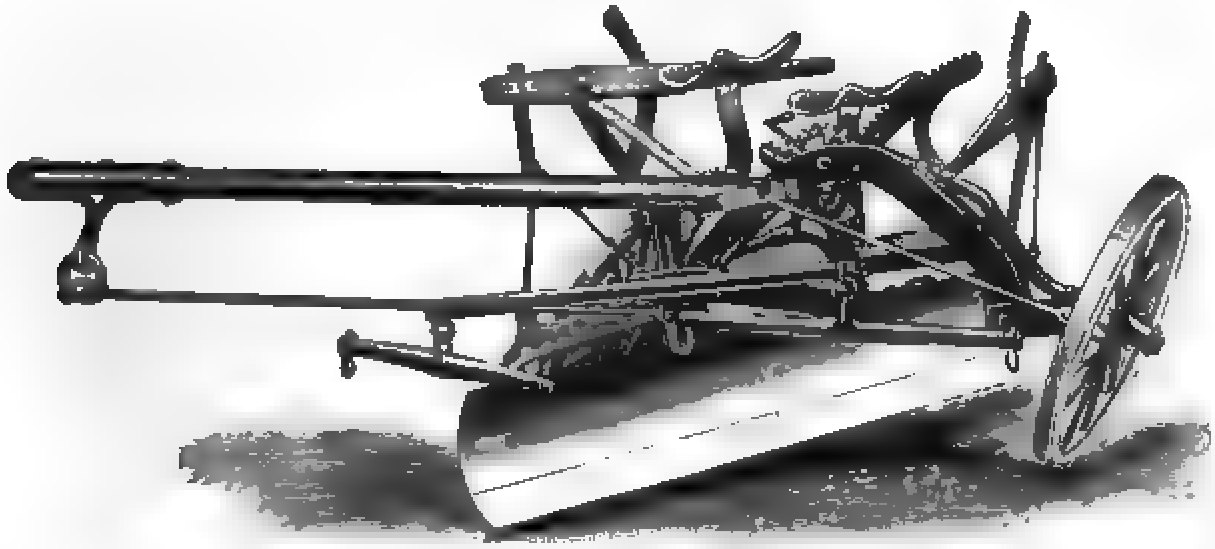


FIG. 39.—KENNETT-SQUARE ROAD LEVELER.

surface to the road, and since the blade of the two-wheel machine has a tendency to work into or out of the ground and thus form scallops in the surface of the road.

202. Scraping Grader. In late spring, after the ground has settled, roads should be prepared for summer travel by being shaped up with the scraping grader (§ 142). When this work is to be done, the ground is comparatively dry, and consequently the heavy scraping grader is required and can be handled on the roads. It is somewhat unfortunate that this tool is ordinarily called a road grader, since the name has possibly led to a misconception as to an important use of the machine. As an instrument of road construction, this machine is used to give a crown to the road; but as an instrument of maintenance, it should be used only to smooth the surface and restore the original crown. Apparently some operators assume that the machine is not to be used except to increase the crown of the road; at least since the introduction of this road machine there has developed a strong tendency to increase the crown unduly. Side slopes steeper than just enough to turn the water into the side ditches are a detriment. Other things being equal, the best road to travel on or to haul a load over is a perfectly flat one.

203. *Operating the Scraping Grader.* To smooth the road, the machine should be run over the ground so as to plane off the ridges and fill up the ruts. Commence at the ditch and work toward the

center, scraping with the entire length of the blade. The blade should stand nearly square across the road, and considerable earth should be shoved along in front,—enough to fill the depressions;—but only enough earth should be moved toward the center of the roadway to re-place that washed down by the rains. The surplus earth should be uniformly distributed along the surface, by carrying the rear end of the blade a little higher than the point. A ridge of earth should not be left in the center of the road, since it will only slowly consolidate and is likely to be washed into the side ditches to make trouble there.

This work should be done early—before the ground becomes hard and difficult to work, before traffic has been compelled partially to do the work of the road leveler, and while the surface is in condition to unite with the loose earth left by the machine, and when the roots of grass and weeds do not interfere with the work of the blade. Unfortunately this work is often postponed until the ground is so hard that it is impossible to do a thoroughly good job. If the ground is a little too wet for tillage, it is all the better for road making, since it will pack and harden better than though it were drier. After the ground becomes dry and hard, it is not only more laborious and expensive to secure a smooth surface; but the newly repaired road may for weeks be in a worse condition than before it was worked, since the loose earth is too dry to pack under traffic.

If during the summer the road becomes badly rutted, the scraping grader should be lightly run over the surface—preferably when the road is a little damp. A little timely work done in the right way is like "the stitch in time that saves nine."

204. A common error in scraping roads is not to begin far enough down in the ditch, thus leaving a shoulder which prevents the water from flowing from the roadway into the side ditch. Fig. 40 shows a road finished in this way. The shoulders not only dam back the water, but also narrow the roadway; and after weeds and grass have got a good start, it is improbable that the shoulder will be cut off next time the road is scraped, and in all probability each successive scraping will make a bad matter worse. However, with a skilful use of the scraping grader these shoulders can be cut off (see Fig. 31, page 107).

205. Not infrequently writers claim that material from the side ditches should not be placed upon the roadway. Unquestionably silt from the bottom of the ditches is undesirable material with which to build or repair a road; but in ditches properly constructed and cared for, there is not much, if any, of such material, and if any of it is removed with the scraping grader it is so thoroughly mixed with good material before it reaches the roadway as to be practically harmless. The advice against fine material from the side ditches originated when the drag scraper was the chief tool used in

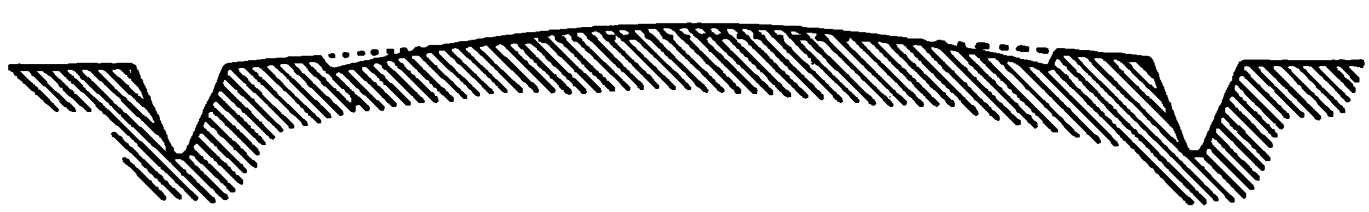


FIG. 40.—OBJECTIONABLE SHOULDERS LEFT BY SCRAPER.

repairing roads, and the advice has unfortunately outlasted its usefulness.

206. *Cost of Scraping.* To shape up the road in the spring, six horses and three men are required to operate the scraper. The wages of a team and driver will usually be $3.00 or $3.50 per day, since generally the scraping should be done when farmers are busy with farm work, and since the work is hard on teams. The cost of operating the grader is then $9.00 to $10.50 per day. A scraper will on the average smooth up 3 or 4 miles per day, at an expense of $3.00 to $3.50 per mile, or, in round numbers, including repairs and loss by bad weather, say, $4.00 per mile. If the road is not very rough two rounds are enough, and if it is very bad four may be required, but on the average three rounds are sufficient. If the work is postponed too long, the cost may be nearly double the above. Not infrequently a traction engine can be hired cheaper than horses; and if the roads are not too rough or too soft, the engine is better than horses.

The cost of smoothing up city streets would be considerably more than the above, because of the time consumed in passing sidewalk crossings or in turning to avoid them. However, the amount of work accomplished in a day depends greatly upon the training of men and horses. In a particular case, city teams were employed to scrape city streets, and with every appearance of an honest effort only fifteen blocks were shaped per day. Under the same

conditions, country teams smoothed twenty-five blocks per day with seemingly no unusual effort.

207. The actual cost for country roads is often much greater than the above, particularly when the work is done under the road-tax system, since frequently when the operator is ready to work he must go several miles for the grader and then finds that it is in use or is somewhere else; and, perhaps, when found he discovers that the blade must be taken to the blacksmith shop to be sharpened. The remedy for this state of affairs is in better road administration and in having more machines. The number of miles of road which one machine will serve will depend upon the nature of the soil, the amount of travel, the condition in which the roads are kept, the amount of use made of the harrow (§ 195) and of the railroad rail (§ 196), and upon whether the roads are maintained under the labor-tax or the cash-tax system (§ 52). On the prairie of the Illinois corn-belt one machine is sufficient for 15 to 25 miles of road.

208. Rolling. Many writers recommend the use of a roller in maintaining earth roads. Unquestionably the more compact the road-bed the better, but the advantage secured by rolling is not worth the cost. The only time when a roller would have an appreciable effect would be early in the spring, just after the frost has gone out of the ground; but clearly it would be impracticable to use the roller before the surface has been smoothed with the scraping grader; and after the surface has been smoothed up by planing off the ridges and filling up the hollows, the roller would simply ride on the ridges and practically not compact the road at all—at least not where most needed, i. e., in the hollows. It is not known that the roller was ever tried in maintenance—at least several writers who have recommended it highly for this purpose say that they do not know of its ever having been so used. See § 130.

209. Filling Holes. After the road has been smoothed by the scraping grader, it is a good plan, particularly if the road is very rough, to send a man with a shovel to fill up all ruts and depressions that were too deep to be filled by the scraper. The cost is small, but the benefit is very great. If a deep hole has been filled by the scraper, it is well to add a little more earth to provide for settlement in order to prevent the re-appearance of the hole. The new material should be trodden or tamped solidly into place.

Holes and ruts in an earth road should never be filled with stone, brick, or coarse gravel. The hard material does not wear uniform with the rest of the road, but produces bumps and ridges, and usually results in making two holes, each larger than the original one. It is a bad practice to cut a gutter from a hole to drain it to the side of the road. Filling the hole is the proper course, whether it is dry or contains mud.

If the scraper has left any shoulders next to the side ditches (see 204), they should be carefully removed with the shovel. Frequently there are holes at the end of bridges and along the side of small wood-box culverts which require attention. Finally, during the fall the roads should be repaired with special reference to getting them into good shape for the winter. Any saucer-like depressions or ruts should be filled with earth like that of the road-bed.

210. Removing Stones. Bumping along over stones is hard upon the rider's back, a strain upon the vehicle, trying on the team, and damaging to the road. All loose stones larger than one inch, or at most two inches, in diameter should be taken entirely away or be piled beyond the side ditches; and stones projecting above the surface should be dug out. Usually the stones can be removed with comparative ease. They should never be left just outside of the trackway, as is sometimes done, to restrict traffic and to obstruct the flow of water from the center to the side ditches.

Not a few inhabitants of towns and villages consider it legitimate to throw brickbats and stones from their yards into the street. This practice deserves severe condemnation. Many streets could be materially improved at small expense, both in appearance and for travel, by the removal of all stones and bricks.

211. CARE OF SIDE DITCHES. The side ditches should be examined in the fall to see that they are free from dead weeds and grass; and late in the winter they should be examined again to see that they are not clogged with corn stalks, brush, etc., washed in from the fields. The mouth of culverts should also be cleared of rubbish, and the outlet of tile drains should be opened. Attention to side ditches will prevent overflow and washing of the road-bed, and will also prevent the formation of ponds at the roadside and the consequent saturation of the road-bed. The road care-taker should frequently go over his portion of the road just as a heavy

fall of snow is going off, for it is then that the most damage is done by water.

212. CARE OF ROADSIDE. It is desirable that the roadside should be so cared for as to secure a coating of grass instead of unsightly and noxious weeds. This can usually be accomplished with an occasional mowing with but slight expense.

213. Care of Trees and Hedges. Earth roads should have plenty of light and air. Trees along the road may add beauty to the landscape (§ 184), but shade is nearly sure to breed mud holes. In some localities and under some conditions, shade upon the road surface should be practically eliminated by cutting down the trees or by trimming them so as not to keep the breeze and sunlight from the road; but in other localities and under other conditions, a little of the utility of the road may be sacrificed to secure attractiveness in the general surroundings.

A tall hedge cuts off the view of the adjacent country, shuts out the breeze, in a dry time keeps in the dust, and in a wet time retards the drying of the road. The hedges usually belong to the adjacent private property, but in most states the height is limited by statute; and in such cases the road officials should enforce the law. If there is no law governing hedges and trees near the road on private property, the road officials should use all possible diplomacy to have trees and hedges trimmed with reference to the benefits of the road. In this connection, see § 214.

214. OBSTRUCTION BY SNOW. In localities subject to heavy falls of snow, it is an important matter to keep the roads from becoming obstructed by it during the winter. In some countries where there is only an occasional fall of snow, as in France, it is customary to remove it from the surface of the road; but where there is much snow, it is only necessary to compact it so as to make the road passable. This is done by driving horses or cattle back and forth along the road, or by rolling the road with a heavy farm-roller. The use of the roller should commence with the first storm of the season and be continued as often as necessary through the winter. In the case of a very heavy storm, the roller should be sent over the roads at intervals during its continuance. Obviously this work must be done by the residents along the road.

Snow and ice frequently accumulate in the side ditches to such a

height as to make the surface of the road the principal line of drainage. In the spring, when this occurs on earth roads, a large volume of snow-water flows down the road, and often seriously damages it by washing gullies in the surface. Even the best broken-stone roads may be seriously injured in this way; and in some localities it is necessary to remove the snow from the side ditches to prevent damage of this character. The difficulty and expense of keeping the side ditches free from snow and ice is greatly increased, if the ditches are deep and narrow, particularly since with this form of ditch it is necessary to maintain a culvert or covered gutter at the junction of cross roads and private drives with the main highway. These culverts are very liable to become clogged with icy snow, and it is nearly impossible to clear them without digging them up—which is rarely practicable. This difficulty could be obviated, or at least greatly decreased, by constructing shallow ditches; and, if necessary, laying a large tile drain under the ditch to carry the surface water.

The cost of work occasioned by snow can be decreased by proper attention to the fences, underbrush, etc., along the side of the road. Snow drifts are caused by the obstruction of the currents of air near the ground—those that carry the drifting snow. In forests the winds do not have sufficient velocity to carry the snow, and consequently it lies evenly and of a uniform depth; but in the open country it drifts with the wind. Fences and shrubbery which retard the winds but permit the snow to blow through, cause the snow to pile up on the sheltered side and possibly to block the road and ditches. The fences should be either entirely open or very close. A high tight fence obstructs the wind, and causes the snow to pile up on the windward side. If the roadside is partially obstructed, the wind moves the loose snow into earth cuts and also into the beaten snow path, and fills them up. Filling the snow trackway gradually raises the traveled portion of the road until turning out into the loose snow becomes dangerous.

215. In Vermont, "in many townships the cost of keeping the roads passable in the winter is one third, and in some one half, of the total amount expended on the highways, and the average for the state is one eighth," or $4.30 per mile per annum.*

* Report of Vermont Highway Commissioners, 1896, p. 17–18, and Table D.

216. The possible cost of maintenance on account of snow should be considered in locating a road (see § 93).

217. Prevention of Dust. Loam and clay roads are improved by a little moisture—just enough to keep them damp and dark without making them soft or spongy. In dry climates the roads not only become excessively dusty, which is a great discomfort, but also wear into pot-holes, which are dangerous, since being filled level-full of dust their presence is not revealed until a wheel or a horse's foot plunges into them. In some localities the dust at times is practically hub deep, and is not only an annoyance but greatly increases the tractive resistance. In arid climates and even in dry times in humid climates, sprinkling is an effective means of maintenance. A layer of straw is sometimes put upon the road to subdue or prevent the dust; but of course the effect is only temporary.

218. Oiling the Road. Recently crude petroleum has been employed on wagon roads, instead of water, to prevent dust—in southern California practically, and in several other states experimentally. Oil has been used by a number of railroads to reduce the dust raised by trains—particularly near passenger stations. When applied to wagon roads, oil reduces the dust, makes the roadbed at least partially non-absorbent, and gives a dark-colored surface which is more pleasing to the eye than the ordinary light, dusty soil. A further advantage gained from a practically dustless road is the prevention of dust upon fruit trees and upon park foliage.

The oil is applied preferably at a temperature of 200° F. or over, with a sprinkling wagon. Oil should not be applied to a hard surface to prevent dust, since it is not readily absorbed and does little or no good. The road should be perfectly dry, and the oil must be thoroughly incorporated with the dust. If it is merely sprinkled on the surface, only the top layer of dust will be impregnated; and the wheels will break up the crust thus formed and expose the dust below, and the road will be but little, if any, better than before treatment. After the oil has been applied, the surface is stirred with a light harrow, to mix the dust and the oil.

On the sandy soil of southern California, the first application usually consists of 4,000 to 6,000 gallons to a mile of road 16 to 18 feet wide, or $\frac{3}{4}$ to $1\frac{1}{4}$ gallons per square yard. If the surface is very

loose more than 1½ gallons may be required to keep down the dust. The rule is to apply in the first application all the oil the road will absorb. The road is sprinkled two or three times during the summer, the quantity of oil required for the second and third application being much less than for the first. The oil used is the residuum remaining after the naphtha, gasolene, and kerosene have been extracted from crude petroleum, and contains 17 to 18 per cent of bitumen (§ 570). The latter is the most important constituent. The oil costs in southern California from $1.00 to $1.25 per barrel of 24 gallons f.o.b. at the refinery; the outlay is about $200 per mile of 16-foot trackway for three applications, of which about $15 to $20 is for the labor necessary to apply the oil.

219. The application of oil decreases the tendency to form mud, since it aids the road in shedding rain water, and also since the bitumen in the residuum cements the particles of the soil together and increases its resistance to being cut up by traffic. However, the tendency of oil to decrease mud is only slight, and the effect of the oil will not last through a wet time. Oiling the road is most needed and is also most effective in a dry climate. The best results are obtained on a clay soil or on sandy or gravelly loam; and oil is ineffective on fine sand, coarse gravel, or alkali soil.

Residuum oil seems to be very beneficial to macadam roads (see § 381).

220. Cost of Road Maintenance. In § 51 are given a few data on road expenditures in different states; and in Table 16, page 142, are details of the expenses for roads in Champaign County, Illinois. Notice that part of the expenditures in Table 16 are for maintenance proper, while part are for improvements in the original construction.

It is not known that any data similar to those in Table 16 were ever before collected, and hence there is no means of knowing whether these data are representative. It is probable that the expenditure for bridges is considerably larger than the average. Champaign County is a rolling prairie situated in the corn belt. There are no large streams, and practically all the land is under cultivation. Farm lands without buildings sell at $80 to $100 per acre. There are 1.97 miles of road per square mile of area outside of cities and villages. All the roads have a black loam surface.

TABLE 16.

AVERAGE EXPENDITURES PER MILE OF EARTH ROADS IN CHAMPAIGN CO., ILL.

1. New steel bridges—exclusive of county aid*	$16.20
2. Drainage	6.32
3. Tile culverts	1.32
4. Repairs of bridges and culverts	2.93
5. Grading (not simply smoothing and leveling)	1.43
6. Smoothing and leveling (not grading)	2.83
7. Mowing the roadsides	1.14
8. Administration	2.69
Total	$34.86

221. ROAD ADMINISTRATION. The condition and cost of roads are largely dependent upon the efficiency of the management of road affairs. For a discussion of Road Administration, see § 43–55. It is believed that the matters referred to in § 46 are important means of stimulating an abiding interest in good roads and of increasing the knowledge of how to construct and maintain them.

222. MAINTENANCE BY CONTRACT. In view of the ordinarily inefficient system of caring for roads, it has frequently been proposed to maintain them by contract. As a rule, work done under the supervision of a contractor who has pecuniary interest in the result is more economical than that performed under the direction of a public official; but it is not wise to do work by contract unless the amount required can be approximately known beforehand, and also unless the character of the performance can be easily determined after completion. Neither of these important conditions would be present in a contract for the maintenance of a public highway. Owing to the indefiniteness as to the amount and character of the work to be done, it is not at all certain that the maintenance could be provided for by contract for a sum less than the public officials could do the work under the present system. The inspection would finally depend upon the road official, and the letting of a contract would increase the difficulties and expense of supervision.

Under the present system those who perform the road labor have an interest in the resulting condition of the roads, while the

*In Illinois the county pays half the expense of bridges costing more than a specified per cent of the assessed value of the township. The expenditures by the county for new steel bridges is nearly as much as by the township.

contractor would be interested only in doing the work for the least money; and therefore the roads would probably be worse under the contract system than under the present system.

It is claimed that the contractor could maintain a trained corps, and therefore do better work than can be obtained by the present system. This would possibly be true if the amount of work to be done were sufficiently great; but the data in Table 16, page 142, shows that the amount of work remaining to be done by contract is very small. The expenses for bridges and drainage almost certainly represent contract work, and a large part of the expense for "tile culverts" and for "repairs of bridges and culverts" is for material. These items and the cost of administration constitute eight tenths of the expenses reported in Table 16. The remaining items represent an expense for labor of only about $6.00 per mile; and therefore the ordinary expenditure for the care of earth roads is too small to justify maintaining a corps of expert road workmen. Further, leaving the road work to a comparatively few trained attendants would result in a great waste of time in traveling to and from the work. Again, the attendant would have so many miles of road under his care that he could visit any particular piece only at long intervals; and therefore could not do the work at the most favorable time, and could not become intimately acquainted with the road—conditions absolutely necessary for proper maintenance. These objections have less force as road expenditures increase and as the money is concentrated on a comparatively few roads. Finally, a large proportion of the roads have an earth or gravel surface, and the labor required for their care is similar to that with which the farmer is familiar; and therefore he is not lacking in the skill required in maintaining them. The farmer who travels a particular road frequently and in all kinds of weather, has a more intimate knowledge of it than the man who sees it only occasionally; and therefore for this reason the farmer is best able to care for the road. Besides, the farmer uses the road more than anybody else, and he alone pays for it. [1] See paragraph 3 of § 46.

The system of employing a man to give his entire time to the road is almost a necessity with first-class broken-stone roads, whose maintenance requires intimate knowledge and constant attention, but the system is not applicable to earth roads.

Art. 3. Sand Roads.

223. In most localities roads on pure sand are the worst in existence, since they are good only when wet, and therefore are at their worst most of the year; while clay or loam roads are at their best most of the time. If the sand is fine, a dry sand road is worse than any muddy road.

224. Drainage. Roads on pure or nearly pure sand require very different treatment from those on clay and loam. Dampness improves a sand road, while it damages a clay or loam road; and therefore the preceding rules for the drainage of loam or clay roads must be reversed for sand roads. Wet sand makes a better road than dry sand, and therefore draining a sand road is useless and possibly a damage. Of course, this is not true of quicksand, since that is improved by drainage; but there is very little, if any, of such material in the roads.

225. Grading. Sand roads are usually nearly level longitudinally and need little, if any, grading. They should not be crowned, since they do not need surface drainage. The traveled portion should be simply leveled off.

226. Shade. While shade harms a loam or clay road, it improves a road of sand or broken stone, since it prevents the evaporation of the moisture from the road-bed. Therefore a sand road can be permanently improved by planting trees so as to shade the traveled way. They will prevent, in part, the drying effect of the winds, as well as intercept the rays of the sun.

227. Hardening the Surface. The great disadvantage of pure sand as a road material is the freedom with which the grains move one on the other; and therefore to improve a sand road grass should be encouraged to occupy all the space possible, since its roots will decrease the movement of the grains under the tread of the hoofs and wheels. It is an advantage if low growing bushy vegetation occupies the surface clear up to the traveled way—both for the shade and for the binding effect of the roots and the leaves. The leaves fall into the ruts and also aid in binding the sand.

Where no other recourse is possible, it is advantageous to have two roadways adjacent to each other, one of which is planted with grass while the other is in use. If the traffic is not very great the

effect of the grass will last for a year or two after the road is again used by the wheels. A fertilizer is sometimes applied to stimulate a growth of grass upon the wheelway. In some localities the sand is so fine that it drifts like snow, and fills the partially hardened way, in which case the road is improved by planting the roadsides with grass to prevent the sand from blowing.

A road on pure sand is improved temporarily by covering it with a thin layer of any vegetable fiber, as decaying leaves, straw, marsh hay, waste from sorghum mills (begasse), fibrous or string-like shavings, etc. This fibrous material soon becomes incorporated with the sand and decreases its mobility; but the vegetable matter wears out and decays, and consequently the effect is only temporary. The length of time such expedients will last depends upon the climate and the amount of travel. Sand roads improved with three to four inches of shredded wood (excelsior) have kept in reasonably good condition for a year or two.

The only permanent improvement possible for a sand road, aside from substituting an entirely new wearing surface, is to add a thin layer of tough clay, and incorporate it with the sand—either by traffic or with a harrow or a corn cultivator. This is expensive at best, and it is difficult to get the sand and clay thoroughly incorporated in the right proportions; but the result is permanent.

228. In this connection it is a significant fact that the sand shoulders of a broken-stone road soon become firm and hard, owing to the infiltration of the fine dirt and stone dust washed from the surface of the roadway. The fine particles of dust between the grains of sand act mechanically to decrease the mobility of the sand, and also increase capillary attraction and diminish percolation, which in turn also keeps the sand damp and still further decreases its mobility. Apparently, then, the incorporation of fine dust in a sand road would improve it; but it would be difficult to procure sufficient dust for this purpose.

CHAPTER IV.

GRAVEL ROADS.

230. Gravel may be defined as a mass of small, more or less rounded fragments of stone which have been broken out and shaped by the action of water or of ice. When properly applied gravel makes an excellent road surface,—superior to ordinary earth but not possessing the wearing qualities of first-class broken stone. Gravel has an advantage over artificially broken stone that the former is already prepared and is therefore the cheaper. A gravel surface is most suitable for country highways not having exceedingly heavy traffic, for unfrequented streets in villages and small cities, and for park roads.

Many of the principles of construction are the same for gravel roads as for broken-stone roads; but usually the latter are much more elaborately constructed than the former, and therefore the two will be discussed separately.

ART. 1. THE GRAVEL.

231. REQUISITES FOR ROAD GRAVEL. To be suitable for road-building purposes, gravel should fulfill the following conditions: 1. The fragments should be so hard and tough as not easily to be ground into the dust by the impact of wheels and hoofs. 2. The pebbles should be of different sizes, each in the proper proportion. 3. There should be intermixed with the coarser particles some material which will cement and bind the whole into a solid mass.

232. Durability. From the nature of their origin, it is apparent that gravel may differ widely in the nature of the stones composing it. Not only do different gravels differ from each other, but any particular gravel may be composed of fragments of a variety of

rocks. Having been transported a considerable distance by water and ice, gravel is usually fairly durable, since the softer and more friable fragments have been worn away. Although gravel is not equal to the best crushed stone for road building, in many parts of the country the rocky fragments transported by water and ice are more durable than any of the native rocks.*

233. Sizes. If the pebbles are too large, the road will not be homogeneous, and the large stones will work to the surface under the action of traffic and frost; but, on the other hand, if the pebbles are too small, the gravel will partake too much of the character of sand, and will be difficult to bind properly. The best results are obtained when the largest pebbles are not more than ¾ to 1 inch, or at most 1½ inches, in greatest dimension. With stones larger than 1 inch, it is difficult to keep the surface from breaking up when dry. Small gravel makes a pleasanter road and one that is easier to keep in order. If stones larger than 1½ or 2 inches are present, they may be screened out and used in the foundation (§ 257).

It is desirable that the several sizes should be so proportioned that the smaller ones are just sufficient to fill the interstices between the larger ones, since then less binder is required. The binder is usually the least durable ingredient, and hence the less there is of it the better. Gravel can often be improved by screening—either to remove an undesirable size or to separate it into several sizes afterward to be combined in new proportions. The proper proportion depends upon the nature of the gravel—whether the binding material is already present in the form of dust, or whether some of the pebbles must be crushed to produce the binder.

234. Binder. The most important requisite for good road-building gravel is that it shall bind or pack well. If it does not pack well, the wheels will sink into the gravel and increase the force of traction, and the rain water will penetrate the road-bed and soften it. To bind well, the several fragments should be in contact with one another at as many points as possible, in order that they may be firmly supported, and that friction may act to the best advantage to resist displacement. To secure contact at every point, all the

* For a discussion of the merits of the principal stones for road-building purposes, see Art. 1, Chapter V.

interstices between the fragments should be filled—those between the large pebbles, with small pebbles; those between the small pebbles, with sand grains; and, finally, those between the sand grains, with some finer material, called a binder. The binding material must be very finely divided, so that it can be worked into the smallest interstices; and for this reason, it is the least durable part of the gravel, being easily washed out or blown away. For the best results, then, the sizes of the coarser particles should be so adjusted as to require a minimum amount of binder.

The binding material may consist of clay, loam, silica, stone dust, iron oxide, etc., or some ingredient which will crush under traffic and furnish a fine dust.

Clay is by far the most common binding material; but the only recommendations for it are (1) that it is easily reduced to an impalpable powder by the action of wheels or by water, and (2) that it is often found already mixed with the gravel, and (3) that if it must be artificially mixed, it is plentiful and cheap. Clay is an undesirable binder, since its binding action depends in a large measure upon the state of the weather. During a rainy period it absorbs water and loses its binding power, and the road becomes soft and muddy; while in dry weather it contracts and cracks, thus releasing the pebbles and giving a loose surface. Clay is also very susceptible to the action of frost; and consequently when the frost is going out, a gravel road with a clay binder ruts up badly and frequently breaks entirely through. When the weather is neither too damp nor too dry, a gravel road with clay binder is very satisfactory. The clay should be no more than enough to fill the voids in the pebbles and sand, and for a good road-gravel should not exceed 15 to 20 per cent of the mass. Not infrequently much greater quantities of clay are present. This surplus may sometimes be removed by screening; but often it can be removed only by washing—a process which is usually so expensive as to be prohibitive.

Loam is chiefly clay mixed with sand and a little vegetable matter, lime, etc.; and as a binding material has all the characteristics of clay.

A very finely divided silica, easily mistaken for clay, is occasionally present in gravel, and makes an excellent binding material.

Iron oxide is frequently found as a coating on the pebbles in

such quantities as to cement them firmly together. These ferruginous gravels when broken up and put upon a road, will again unite—often more firmly than originally, because of the greater pressure—and form a smooth hard surface, impervious to water. They are much used in road building, gravel from Shark River, N. J.,—much used around New York City—and that from the Ohio river near Paducah, Ky.,—largely used in the neighboring states—being examples.

235. Comparatively coarse gravel frequently contains some ingredients, as, for example, fragments of limestone or shale, which under the action of traffic and the weather reduce to a powder and form a good binding material. Sometimes gravel contains bits of ironstone (clay cemented with iron oxide) in the form of thin flat chips which break and crush easily under the wheels, and if present in any quantity make a most excellent binding material.

236. The binding action referred to in the preceding discussion is mechanical; and we come now to the consideration of an action not yet well understood, but which for the present at least will be called chemical action. Experiments seem to prove that if fine powder of certain stones is wetted with water and subjected to compression, a true chemical cementation takes place. Consequently some stone when broken into small fragments, wetted and traversed by heavy wheels or by a road-roller will be cemented together to a considerable degree. This cementation is due to the fact that the friction of one small piece of stone upon another produces a very fine powder at the point of contact, which, when wetted and compressed, forms a weak cement. Owing to the rounded surfaces of water-worn pebbles, this cementing action is much less with gravel than with rough angular fragments of broken stone; but with gravel composed of undecayed rocky fragments this action takes place to a considerable degree. As a rule, pebbles of bluish color will thus cement together, while reddish or brown ones will not, which accounts in part at least for the well known superiority of blue gravel for road purposes. Trap rock possesses the property of cementation in a high degree, and hence trap gravel is a very excellent road-building material. Limestone possesses a fair degree of cementation, but is too soft to wear well. Quartz wears well but produces little or no dust for cementation, and besides its

surfaces are so smooth and hard that the binder has but little effect; and therefore it rarely happens that a gravel of which more than one half of its bulk is white quartz pebbles proves to be a good road gravel.

The cementation of rocky fragments is much more important in a crushed-stone road than in a gravel one, and therefore the subject will be more fully considered in Chapter V.

237. The binding elements heretofore discussed exist naturally in the gravel; but gravels are often found that do not contain any binding material, and in such cases it is necessary to add some cementing material.

Clay, shale, hard-pan, marl, loam, etc., are often used for this purpose, chiefly because they are so plentiful and easily applied; but none of them are suitable for the purpose, as they all have the characteristics of a clay binder (see § 234). With any of them, it is difficult to keep the gravel from breaking up—particularly under heavy traffic.

In some localities a poor iron ore is found, which, when mixed with gravel, makes an excellent binder and gives a smooth hard road surface. Bog iron-ore, which occurs in marshes, is usually very good for this purpose.

The fine dust from a stone crusher, when mixed with gravel, will bind it together; but it is seldom feasible to use stone dust on account of the expense. When this method of binding gravel is resorted to, the construction partakes of the character of a crushed-stone road—a subject foreign to this chapter. The chief difference between a gravel and a crushed-stone road is in the thoroughness of the binding. The binding of a gravel road is due chiefly, and usually solely, to the mechanical action of the binder; while the binding of the broken stone is due to both the mechanical and the chemical action of the binder, and both are stronger with rough angular fragments of broken stone than with water-worn pebbles.

238. DISTRIBUTION OF GRAVEL. The gravel beds of the glacial drift furnish excellent road-making materials. The glacial ice sheet, often a mile or more thick, covered New England and Canada and all of the United States north of an irregular line starting on the Atlantic Coast a little south of New York City and running thence successively to the southwest corner of the State of New

York, to Cincinnati, to a point a little north of the mouth of the Ohio river, to the mouth of the Missouri river, to Topeka, Kansas, thence north and west a little west and south of the Missouri river to the head waters of that stream, and thence west to the Pacific ocean. All of the area north of the above described line was covered with the ice sheet except small portions of southeastern Minnesota, northeastern Iowa, northwestern Illinois, and a considerable portion of southwestern Wisconsin. As this ice sheet crept to the southward, it rent great quantities of stone from the bed rocks; and these materials were borne southward, either in the slow-moving ice or hurried along by the violent currents of water which swept forward to the margin of the ice field. Thus impelled the under-ice streams were able to bear toward the margin of the glacier great quantities of stone. The original range of the glacial gravels has been greatly extended here and there by the streams, which, flowing southward beyond the drift belt, have often carried quantities of the hard detritus for many miles beyond the limits of the ice-field.

Unfortunately the glacial gravel deposits have not been studied from the point of view of the road-maker. However, it is known that east of the Hudson river the glacial supply of road gravels is only here and there of economic importance, for in most of that field the glacial waste lies on native rocks which are suitable for road-making; and that from the Hudson to the Mississippi, the glacial deposits of bowlders and gravel afford better road-building materials than any of the native rocks. Glacial gravels exist in considerable quantities in western Pennsylvania, in the greater part of Ohio, in northern Indiana, and in northern Illinois, and to some extent in several of the states of the Northwest.

239. South of the glacial district, the rocks exposed to the weather have decayed by a process of leaching, which in many cases has removed strata hundreds of feet thick. The rocky portion is removed in proportion to its solubility; and, as a result, there are often left concretions of cherty matter which were originally contained in beds of limestone. This cherty residuum of flinty material generally lies in a comparatively thin sheet of fragments mingled with sand and clay; but occasionally it is found in deposits from which the clay and sand have been removed by recent or

ancient streams, leaving the material well suited for spreading upon a road. Sometimes this cherty residuum is found in layers of fragments many feet thick, and is valuable for road-building in a locality where suitable material is scarce. The presence of chert is often revealed by the gullies in the plowed fields and along the streams. In some localities very good roadways are constructed simply by shoveling these fragments from the stream beds and depositing them on the road.*

This cherty deposit is a valuable road material in the southern portion of the Appalachian mountains, and along the Ozark foothills in southern Illinois (particularly in Alexander and Union counties), in southern Missouri, and in northern Arkansas. Chert is found in some of the states of the Northwest where the glacial erosion was small, so that the rocks that had decayed before the glacial time were not entirely removed. In southwestern Arkansas the gravels consist of fragments of novaculite or razor stone—a material of nearly the same geological origin and physical characteristics as chert. In many places in that state the novaculite gravels form extensive beds, 20 or more feet thick. At the southern extremity of the Appalachian mountain system is a wide-spread deposit of gravel, termed the La Fayette formation, whose geological origin is not determined. This deposit often attains a thickness of 40 to 50 feet, and is a valuable source of road-building material.

240. If gravel be defined as material prepared by nature ready to be laid upon the road, then a few words are in place here concerning iron ore. In some localities there are low-grade iron ores which, owing to the admixture of various impurities, are unfit for use in making iron, that may be valuable for road building. These low-grade ores are widely distributed; and generally wherever limestone occurs below a considerable thickness of sandstone, the upper portion of the limy layer will be found to contain iron, and will probably make a fair road material. A lean iron ore is frequently found in marshes; and this variety, known as bog ore, usually makes excellent roads, since it crushes readily and gives a smooth hard surface.

* For a discussion of chert as a road-building material, see § 296.

241. Exploring for Gravel. In searching for gravel in the glaciated district, the following suggestions by Professor Shaler * will be useful.

"In the process of retreat of the ice, the deposits which it left were accumulated under several quite diverse conditions. One of these produced the till, or commingled coarse and fine materials, which had been churned up into the ice during the time of its motion, and came down, when the melting occurred, as a broad, irregularly disposed sheet which, with rare exceptions, is to be found in all parts of the glaciated district, save where it has been swept away by streams.

"Again, from time to time during the closing stages of the ice age, the prevailingly steadfast retreat of the ice was interrupted by pauses or re-advances. In these stages there was formed along the margin of the ice-field what is called a frontal moraine, composed of debris shoved forward by the glacier or melted out of it along its front. These moraines are in most cases traceable, where they have not been washed away or buried beneath later accumulations, in the form of a ridge-like heap of waste, which, as we readily note, contains much less clay and sand and therefore a larger proportion of gravel and bowlders, than the sheet-like deposit of till above described. In some cases these moraines are very distinct features in the landscape, appearing, from the number of large bowlders which they expose, much like ruined walls of cyclopean masonry. More commonly they are found in the form of slight ridges, which may be covered with fine material, but commonly exhibit here and there projecting bowlders. In general it may be said that the moraines afford much better sites for pits from which road materials are to be obtained than the till, and this because of the prevailing absence of clay and sand in the deposits.

"Here and there in almost all glaciated districts, especially in the valleys of the greater streams, there may be found narrow ridges, often of considerable height, and almost always extending in the direction of the ice movement. These ridges are generally termed by geologists eskars, and often have a tolerable continuity for

* American Highways, N. S. Shaler, Professor of Geology, Harvard University, p. 71–73.

scores of miles at right angles to the ice front. A section of them shows generally a gravelly mass, nearly always free from clay and often containing little sand, though occasionally there is an abundance of large bowlders, which have a prevailing rounded or water-worn form. These eskars were doubtless formed in the caves beneath the ice through which the ancient sub-glacial streams found their way. These under-ice rivers were much given to changing their position, and as a stream lost its impetus it was apt to fill its ancient arched-way with debris, which in its time of freest flow would have been sent forward to the ice front. At many places in New England and in New York these eskars contain large and useful deposits of gravel, and also occasionally quantities of bowlders well fitted for crushing as regards their size and hardness. In the Western States, because of the general coating of deep soil, these eskars are less easily found; but they exist there, and should be sought for.

"Where the eskars terminate, as they commonly do, on a morainal line, there is almost invariably found, immediately in front of their southern terminations, a delta-like deposit which, though generally composed in large measure of sand, frequently contains near the moraine extensive accumulations of useful gravel and small bowlders which are fit for crushing.

"Information may be had from the banks of streams, where by chance they have cut below the deep coating of fine materials. The existence of any distinct uprise of the surface affords some reason to expect that the coarse glacial waste may be at that point not very deeply hidden. It is probable that the best method of exploration is by any simple form of drill. Even the ordinary post-hole auger may be made to serve the purpose."

242. CHARACTERISTICS OF DIFFERENT GRAVELS. Any gravel which stands vertical in the bank, showing no signs of slipping when thawing out in the spring, requiring the use of the pick to dislodge it, and falling in large chunks or solid masses, is sufficiently clean and free from clay for use on the road, and usually contains just enough cementing material to cause it to pack well.

Pit gravel usually contains too much earthy material, and can be greatly improved by screening. Gravel is still being deposited in drifts and bars by streams, and this will be found to partake of

the character of the pit gravel of the locality, except that it generally contains less clay, and may have an excess of sand. This is often called river gravel, and is one of the best sources of road material. Lake gravel varies greatly in character. It is usually free from earth and contains sufficient sharp sand to pack well; but is liable to be slaty—an undesirable quality.

243. Composition of Representative Gravels. In an endeavor to determine the composition necessary for a road-building gravel, samples were obtained of a number of gravels that had given satisfactory service in the road. The samples in each case were selected by a person thoroughly conversant with the use of that particular material, and are believed to be fairly representative.

Table 17, page 156, shows the sieve analysis of these gravels. Each sample was first washed in successive waters until the water remained clear, and then the wash water was allowed to stand until the matter in suspension was precipitated. The precipitate was dried in an oven to dryness and then weighed; and the washed gravel was air-dried, and then sifted and weighed. The per cent of voids in the washed gravel was obtained by comparatively gently ramming the gravel under water in a small metal cylinder, the ramming not being severe enough to crush any of the pebbles or fragments.

Table 18, page 157, shows the results of a mineralogical analysis of such of these gravels as had passed a screen having ¼-inch meshes. The matter recorded in Table 17 as being in suspension is called clay in Table 18, although part of it was doubtless organic matter and part fine sand, but the error is not material.

244. To study these gravels further, each will be considered in order.

1. *Urbana.* This is a screened drift gravel obtained near Urbana, Champaign Co., Ill., which has been used in a few instances on private driveways. Table 18 shows only 3.8 per cent of clay present, which will have only a small binding effect. There is 7.6 per cent of iron oxide (Fe_2O_3) in the clay, but there is so small a proportion of clay in the gravel that the iron contained in it will have an inappreciable binding effect. The principal source of binder is, then, the 65 per cent of ferruginous limestone. Limestone itself when pulverized makes an excellent binding material, and a

TABLE 17.

SIEVE ANALYSIS OF ROAD-BUILDING GRAVELS.

Ref. No.	Size of Mesh.	1. Urbana.	2. Decatur.	3. Lexington.	4. Rockford.	5. Peekskill.	6. Buck Hill.	7. Rock Hill.	8. Shark River.	9. Oaktown.	10. Shaker Prairie.	11. Paducah.	12. Rosetta.
1	Per cent caught on 2-inch mesh	0.0	0.0	0.0	6.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	" " " " 1 " "	0.3	1.1	4.6	35.6	2.1	0.0	0.0	0.0	1.5	9.1	20.5	1.9
3	" " " " $\frac{1}{2}$ " "	9.6	12.2	10.0	23.5	41.3	11.7	3.3	0.8	12.2	12.6	20.5	17.8
4	" " " " $\frac{1}{4}$ " "	13.0	10.5	8.7	7.4	25.5	11.0	13.4	12.7	18.6	9.1	8.8	11.0
5	" " " " $\frac{1}{16}$ " "	41.1	14.8	20.2	9.1	17.8	8.4	25.1	33.2	47.5	21.3	13.8	22.3
6	" " " " $\frac{1}{27}$ " "	12.1	3.9	15.3	3.2	2.2	20.4	14.0	7.4	8.9	9.3	5.2	20.0
7	" " " " $\frac{1}{40}$ " "	3.9	7.8	15.9	2.7	1.8	8.2	7.2	5.5	3.5	9.3	1.9	10.5
8	" " passing $\frac{1}{40}$ " "	16.2	40.0	21.0	8.7	8.4	20.2	16.3	20.0	6.1	18.8	21.8	10.4
9	" " in suspension	3.8	9.6	4.2	3.2	0.9	20.0	20.7	20.2	1.8	9.8	7.8	5.9
	Total	100.0	100.0	99.9	99.4	100.0	99.9	100.0	99.6	100.1	99.3	99.7	99.8
	Per cent voids in washed gravel	25.5	30.5	27.3	29.6	30.5	26.3	34.0	28.2	25.6	24.2	24.5	25.3

TABLE 18.

Mineralogical Analysis of Road-building Gravels.

Ref. No.	Mineral Constituents.	1. Urbana.	2. Decatur.	3. Lexington.	4. Rockford.	5. Peekskill.	6. Buck Hill.	7. Rock Hill.	8. Shark River.	9. Oaktown.	10. Shaker Prairie.	11. Paducah.	12. Rosetta.
1	Limestone,—pure carbonate of lime	.....	21.9	.....	.....	.....	.....	.....	.....	18.9	28.6	.....	.....
2	ferruginous	65.0	8.1	21.0	.....	33.5	.....	.....	.....	.....	.....	.....	.....
3	with iron and silica	.....	.....	.....	73.8	.....	.....	.....	.....	2.0	2.4	.....	.....
4	silicious	.....	.....	58.0	.....	.....	.....	.....	.....	.....	.....	.....	.....
5	Sandstone,—ferruginous	.....	7.1	.....	.....	8.7	.....	.....	.....	0.4	.....	.....	.....
6	finely divided	.....	.....	.....	.....	.....	.....	10.5	.....	0.5	3.7	.....	.....
7	coarse	.....	.....	.....	.....	.....	.....	3.8	.....	.....	.....	.....	.....
8	Metamorphic rock,—iron, silica, mica	.....	.....	.....	.....	4.9	.....	.....	.....	2.0	.....	.....	.....
9	iron, silica, limestone	.....	.....	.....	.....	.....	6.0	.....	.....	4.6	2.7	.....	.....
10	Conglomerate,—iron	.....	.....	.....	1.7	.....	.....	.....	.....	.....	.....	.....	.....
11	limestone and quartz	.....	.....	.....	12.3	.....	.....	.....	.....	.....	.....	.....	.....
12	Crystalline rocks,—acidic	4.6	10.1	1.4	.....	15.5	.....	.....	.....	12.1	11.4	.....	.....
13	basic	4.3	19.7	1.1	4.3	14.2	.....	.....	.....	13.2	13.2	.....	.....
14	Quartz, crystalline	22.2	23.3	13.7	4.6	22.1	73.9	64.3	78.8	38.8	27.8	.....	94.9
15	Chert, ferruginous	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	92.9	.....
16	Shale	.....	.....	.....	.....	.....	.....	.....	.....	5.3	0.7	.....	.....
17	Clay	3.8	9.6	4.2	3.2	0.9	20.0	20.7	20.2	1.8	9.8	7.8	5.9
	Total	99.9	99.8	99.4	99.9	99.8	99.9	99.3	99.0	98.6	100.3	99.7	99.8
	Per cent of iron in the clay	7.6	9.1	9.1	9.4	.....	16.5	18.1	9.9	4.6	6.4	8.1	22.1

small part of the limestone is in the form of flat chips that may be easily crushed under the wheels, but the most of the fragments are rounded and not easily crushed except by comparatively heavily loaded wheels. There is only a small per cent of crystalline rocks present, and these are hard and not readily crushed, and consequently can not materially affect the binding qualities of the mass. The gravel also contains 22.2 per cent of quartz; but this material is very hard and not easily crushed, and besides its dust is almost wholly devoid of cementing properties. Both the quartz and the crystalline rocks are quite sharp and angular, which is a very desirable condition, and aids the binding action of the clay and the limestone dust. This gravel packs only slowly in the road, particularly under the light traffic of a private driveway; but under moderate traffic makes a fairly good road, and is not much affected by freezing and thawing.

2. *Decatur.* This is a gravel much used on the country roads near Decatur, Macon County, Ill., with satisfactory results. This gravel has a comparatively large amount of fine sand. An examination of Table 18 shows that it contains more than twice as much clay as the Urbana gravel, but only about one third enough to fill the voids. A considerable portion of the limestone both of the pure and the ferruginous—a total of 30 per cent,—is in thin friable chips, and is easily crushed by the traffic, thus making an excellent binder. The ferruginous limestone contains an unimportant proportion of iron; but the ferruginous sandstone is heavily charged with iron oxide, which makes a good cementing material. This gravel makes a smooth, hard surface, reasonably free from dust in the summer and mud in the winter.

3. *Lexington.* This gravel is used in and around Lexington, McLean County, Ill., for country highways with entire satisfaction. Notice that the clay is equal to only one seventh of the voids. Nearly all of the 21 per cent of ferruginous limestone consists of thin chips which are easily crushed by the traffic. Some binder is probably obtained from the 58 per cent of silicious limestone. The per cent of crystalline rocks present is very small, and can not materially affect the quality of the gravel. The amount of quartz is less than in the preceding gravels, and is an unimportant element.

4. *Rockford.* This gravel has given satisfactory service in Rockford, Winnebago County, Ill., probably under more exacting conditions than any of the preceding. This is considerably the coarsest gravel in Table 17. Notice that this gravel contains, roughly speaking, only about one tenth enough clay to fill the voids. The chief source of binder is the limestone which exists in the form of pebbles, but contains no considerable amount of iron or silica. The basic crystalline rocks by decomposing may furnish a little binder; but as they are round hard pebbles, not easily crushed, the binder derived from this source can be of no practical importance. A very little cementing material may be derived from the iron conglomerate and also from the limestone and quartz conglomerate.

5. *Peekskill.* This gravel is from Roa Hook, a "point" in the Hudson river near Peekskill, N. Y., and is much used in and around New York City, where it is considered one of the best road gravels. Notice that the clay is less than one thirtieth of the volume of the voids. Considerable binding material is doubtless derived from the ferruginous limestone, which contains a comparatively small per cent of iron. The iron in the ferruginous sandstone is too small in amount to be appreciable. Some binder is doubtless derived from the metamorphosed rocks containing iron, silica, and mica. Notice that there are nearly 30 per cent of crystalline rocks, which upon being finely pulverized will furnish an excellent cementing material, particularly after being decomposed. This gravel requires considerable rolling with a heavy roller to crush the several ingredients and liberal sprinkling to work the pulverized material into the voids, before the mass binds. All the other gravels bind and make fair roads under ordinary traffic.

6. *Buck Hill.* This gravel was obtained from the Buck Hill pit at Tuckahoe, N. J. It was recommended as a representative gravel by Hon. Henry I. Budd, State Commissioner of Public Roads of New Jersey. This gravel consists practically of clay and partially rounded quartz pebbles. The metamorphosed rock is angular and friable. The clay is probably enough to fill the voids when the gravel has been compacted by traffic. This is the first of the samples in which the iron contained in the clay

is appreciable, and the iron doubtless has an important part in binding the road. This gravel is used for road building without rolling.

7. *Rock Hill.* This sample was obtained from the Rock Hill pit at Tuckahoe, N. J., and is substantially the same as No. 6 above, except in having a greater per cent of voids and in containing some sandstone which crushes easily and materially reduces the voids of the gravel after it has been compacted in the road. It is said that the best results are obtained by mixing this and the preceding gravel half and half.

8. *Shark River.* This gravel was obtained from the Manasquan Gravel Co. of Asbury Park, N. J., and is much used in Southern New Jersey and around New York City. It consists wholly of clay and small rounded pebbles of pure white quartz, and consequently the only binding material is the clay and the 2 per cent of iron contained in it.

9. *Oaktown.* This is a gravel obtained from the Wabash river, a few miles above Vincennes, Ind., by dredging, which has been used on the roads entering Oaktown, Knox Co., Ind. There is very little clay in this gravel,—only 7.1 per cent, if the shale be considered as clay, as it is practically. The chief source of binding material is the 18.9 per cent of carbonate of lime, much of which is in the form of flat chips. The metamorphic rocks are also in thin chips, and are easily pulverized. The crystalline rocks and the quartz are comparatively rough and angular. In service the limestone pebbles grind up under traffic, and the road becomes hard and firm, and is not much affected by freezing and thawing.

10. *Shaker Prairie.* This gravel is found in a pit on Shaker Prairie, west of Oaktown, Knox Co., Ind., and consolidates under traffic much more quickly than the preceding, the two being used side by side. This gravel contains only a comparatively small amount of fine sand, being in this respect about on a par with the Peekskill gravel—see No. 5, Table 17. It contains a comparatively large amount of clay, being in this respect similar to the New Jersey gravels—No. 7, 8, and 9 in Table 17 and 18. This gravel has more iron in the clay than any of the samples except the Tuckahoe gravels—No. 6 and 7. The limestone is in comparatively large rounded pebbles, and not specially easily crushed

under traffic. The road is bound almost wholly by the clay and the iron in it and by the pulverized limestone.

11. *Paducah.* This gravel came from a pit about two miles west of Paducah, Ky., on the Ohio river at the mouth of the Tennessee river. It makes excellent roads that pack quickly under traffic and are not much affected by freezing and thawing. The coarse material consists of water-worn chert pebbles, and is cemented by ferruginous clay. The chert is brittle and crushes with a sharp splintery fracture, and consolidates readily under traffic, the sharp angular fragments giving an immobile mass and offering excellent surfaces for the cementing action of the binder.

12. *Rosetta.* This gravel comes from the Rosetta pit at Fort Gibson, near Vicksburg, Miss., and is much used by the Illinois Central Railroad as ballast. It is here included under the belief that it will also make good wagon roads. The quartz pebbles are quite rough and angular, and in the pit seem to be quite firmly cemented together by ferruginous clay.

245. *Conclusion.* From the preceding, the following conclusions may be drawn. 1. The relation between the proportion of voids and the per cent of clay is no indication of the road-building qualities of a gravel, for under traffic some of the fragments may crush and decrease the per cent of voids and at the same time increase the amount of the binding material. 2. The friability of the pebbles has a greater effect upon the road-building qualities of a gravel than the per cent of the voids. 3. The binding material may be clay, or clay and iron, or pulverized limestone, or all of these combined. The less clay the more slowly will the road bind, but the less it will be affected by frost.

A study similar to the preceding will not certainly determine the suitability of a gravel for road purposes, but it will throw valuable light upon its probable behavior in the road. The only sure way to determine the road-building qualities of a gravel is to test it by actual service, for much depends upon the friability of the pebbles, the weight of the traffic, the climatic conditions, etc. In applying the test of actual service, particularly to determine the relative merits of two gravels, account should be taken of (1) the nature of the soil, (2) the care employed in preparing the foundation, (3) the quantity of material used, (4) the amount of traffic,

(5) the care given to maintaining the road, and (6) the length of time the material has been in service. The character of a gravel road is generally indicated by the sound of the metal tires of the wheels of the vehicles passing over it. If the wheel makes a continuous crisp gritty sound, the road is reasonably good; if the gritty sound is absent, there is probably too much earthy matter on the surface; and if the sound is intermittent and discontinuous, there are probably too many large pebbles in the surface material.

ART. 2. CONSTRUCTION.

246. The subgrade for a gravel road should be prepared in substantially the same manner as an earth road (see Art. 1, Chapter III). Indeed a first-class earth road is the best foundation for a gravel road.

247. DRAINAGE. In no case should the drainage be neglected —neither the side ditches nor the underdrainage. With the hard, impervious surface of a gravel road, the water reaching the side ditches is greater than with an earth surface; and therefore the side ditches should be larger for gravel and broken-stone roads than for earth ones.

A gravel road upon an undrained soil entails a needless expense for maintenance, and is never so good as if the road-bed had been thoroughly underdrained. Not infrequently a thin coating of gravel has been thrown upon an undrained foundation, only to sink out of sight in a year or two, and the attempt to secure a gravel road has been abandoned. In such cases a comparatively small expense for underdrainage would have resulted in a fair road instead of a failure. The total amount of good road-building material in the world is small in comparison with the possible future demand, and therefore it is a public misfortune to have any of it wasted in bungling attempts at road building. One purpose of the gravel is to give a more or less rigid layer which will distribute the concentrated pressure of the wheels over a sufficiently large area of the earth foundation to enable it to support the load without indentation. The thickness of gravel required to support the load depends upon the degree of the drainage, since the more water in the earth the less load it can support. Underdrainage costs

nothing for maintenance, and decreases the amount of gravel required, and also the cost of maintaining the surface.

248. The tile should be placed under the side ditches—as described for earth roads (§ 109). Some writers recommend that a tile be laid under the middle of the gravel or broken stone, with the earth sloping both ways to the tile. There are several objections to this construction: (1) sloping the earth is not of much advantage, and (2) it needlessly increases the depth of the gravel or broken stone; and (3) if the road is otherwise well made, the surface should be practically impervious to water. See § 109.

Some writers advocate a tile each side of the graveled portion, with short lines of tile running each way from the center of the roadway obliquely to the side tile, these "miter drains" to be placed 15 feet apart in wet places. Clearly this construction is based upon a misapprehension of the source of the water reaching a drain tile. The water that enters a tile comes from below and not directly down from above. It is abundantly proven that in an earth road needing underdrainage, little or no water penetrates the surface; and with good gravel or broken stone roads there will be still less. Therefore "miter underdrains" below the graveled portion of the roadway are absolutely worthless, and tiles at the edges of the hardened way are no better than tiles under the side ditches.

249. CROWN. The same general principles concerning the crown apply in gravel roads as in earth roads—see § 115–16. The slope of the gravel surface from the center to the side should be at least one quarter of an inch per foot, and it should not be more than three quarters of an inch per foot. The first is about right for park drives, which have light traffic and are well cared for; if the drive is narrow, the crown may be a little greater than this; but if it is broad, the crown should be less, to prevent the surface from being gullied out near the gutters by the water running from the center to the sides. The maximum crown, as above, would be about right for a country gravel road with heavy traffic, or for a street. If the gravel contains an excess of clay, the crown should be greater than the above maximum, as the surface will be liable to rut up.

Frequently gravel roads have an excessive crown, which forces

traffic to use a narrow strip in the center—see § 114. This results from the fact that the gravel is placed thicker at the center than at the edges, upon an earth road which already has some crown; and thus the surface of the gravel is given a greater crown than the original earth road, while a gravel road should have a less crown than an earth one.

For a discussion of the mathematical form of the transverse profile, see § 309–12.

250. FORMS OF CONSTRUCTION. There are two forms of construction of country gravel roads, which differ as to the manner of preparing the subgrade to receive the gravel. In one form the gravel is simply deposited on the surface in a strip along the middle of the former earth road; and in the other a trench is excavated in which the gravel is placed. For convenience of reference the former will be called Surface Construction, and the latter Trench Construction.

251. Surface Construction. The crudest form of this method of construction consists in dumping gravel, as it comes from the bank, in piles in line on an earth road. The quantity of gravel is gaged by dumping a load in one, or two, or three lengths of the wagon. Little or no attention is given to leveling off the top of the piles, and it is not rolled except as traffic is forced upon the ridge when the earth upon the sides gets muddy. For the first year or two after construction, such a gravel road is little if any better than an earth one. The surface is full of cradle holes and is easily cut into ruts; and the loose material absorbs the rain, and becomes mixed with the soil below. If the gravel is good, the road becomes fairly good after the gravel has been packed by travel and after the holes have been filled up by the addition of new material. This form of construction is common where gravel is plentiful, the work usually being done by labor road-tax.

252. Another form of surface construction consists in setting up two lines of plank on edge and filling the space between them with gravel. The gage planks are set on edge, 8, 10, or 12 feet apart according to the importance of the road, and the gravel is filled in between the planks, 8 or 10 inches deep at the sides and 12 or 15 at the center. Of course, when the boards are moved forward to be used again, the edge of the gravel spreads out and

takes the natural slope, and under traffic it spreads out still further. Ordinarily in this form of construction the gravel is not rolled, and there is little or no driving over it by teams engaged in the construction. The only advantage of this method over the preceding one is that it affords a means of gaging the depth of gravel and of determining the quantity used; and the chief objection to it is that when gravel is put on in a thick layer, the lower part is not consolidated well, at least not for a considerable time, and therefore the surface is liable to break up. This form of construction is very common.

253. In the best form of surface construction, the former earth road is first smoothed up with the scraping grader,—if necessary, reducing the crown. If after smoothing the surface with the grader, the foundation is not already firm and solid, it should be rolled. Next a layer of gravel 4, or at most 6, inches deep is spread upon the prepared subgrade, and leveled—either by hand with a shovel and rake, or with a harrow or scraping grader. In dumping from a wagon or cart, the larger stones will roll to the outer edge of the heap, and in leveling the gravel, care should be taken that these are scattered and covered deeply with fine material, for otherwise the road will not have an uniform texture and will wear unevenly, and the large stones are liable to work to the top.

If the teams hauling the gravel are required to drive over that already placed, the road will be consolidated much sooner; but as the tractive resistance on loose gravel is very great, there is some disadvantage in this requirement. If it is to be insisted upon, the construction of the road should begin at the end nearest the gravel. The gravel can be consolidated with a roller, but not as effectively as by traffic, since no roller gives so great a pressure as the wheels of loaded wagons.* Heavy loads should not be permitted to go over the road while the surface is soft, for fear the wheels will cut through and mix the earth and the gravel. While the gravel is being consolidated by the passage of the teams employed in the construction or by ordinary traffic, all ruts should be filled as soon as formed, by the use of a garden rake, and all holes should be filled by shoveling in fresh gravel. The cost of

* For a discussion of the use of a roller on gravel, see last paragraph of § 254.

filling depressions and ruts will be more than saved in future repairs, while a much better road will be the result.

After one layer has been thoroughly consolidated add a second, and so on until the desired depth is reached. The first layer may be the poorer gravel, the best being reserved for the top. All the layers should be added in time to get well packed before the rains and frosts of winter soften the road-bed.

When finished the gravel should be deepest at the center and taper off to the sides. It is immaterial whether the first layer is the widest or the narrowest; there is a little advantage either way. The depth necessary will depend upon the nature of the soil, the quality of the gravel, the amount of traffic, the maximum weight per wheel, and the care given to maintenance; but under ordinary conditions, a depth of 8 or 10 inches of compacted gravel at the center is sufficient. The width should vary with the amount of traffic; but for a country road a depth of 6 inches at 4 or 5 feet from the center is sufficient. For data on the width of the actually traveled way on gravel and crushed-stone roads, see § 306.

254. Trench Construction. In this form of construction, a trench is excavated, 10 or 12 inches deep and of the required width (see § 306), for the reception of the gravel. The bottom of the trench is usually made parallel to the finished road surface by sloping it from the center toward the sides (see § 305). Fig. 41 shows the form when the finished surface is an arc. Fig. 41 is the standard form for state-aid roads in Connecticut, except that the width of the graveled way may be 12, 14, or 16 feet. The crown is $\frac{3}{4}$ inch per foot of distance from side to center, or 6 inches for a 16-foot roadway. There is not much difference whether the road surface is an arc or two planes meeting in the center. The latter is probably a little the better for country roads, although the former is the more common. Notice that in Fig. 41 the intersection of the road surface with the side slope of the embankment, is rounded off somewhat as recommended in Fig. 13 and 14, page 89. The exact method of rounding off the corners in Fig. 41 is not specified. The thickness of the layers as shown is after consolidation.

The bottom of the trench should be rolled to consolidate it and

to discover any soft places in the foundation. After rolling, any depressions should be filled and then re-rolled. The steam roller is better for this purpose than the horse roller, since it is heavier and since the horses' feet do not dig up the subgrade. For a discussion of rollers, see § 336–40. For precautions to be taken in rolling the subgrade, see § 326.

A layer of 3 or 4, or at most 6, inches of gravel is placed in the trench, and the gravel is consolidated either by throwing the road open to traffic or by rolling. The latter is preferable, since teams in passing each other are liable to break down the edges of the trench and mix the earth with the gravel, and since the wheels are

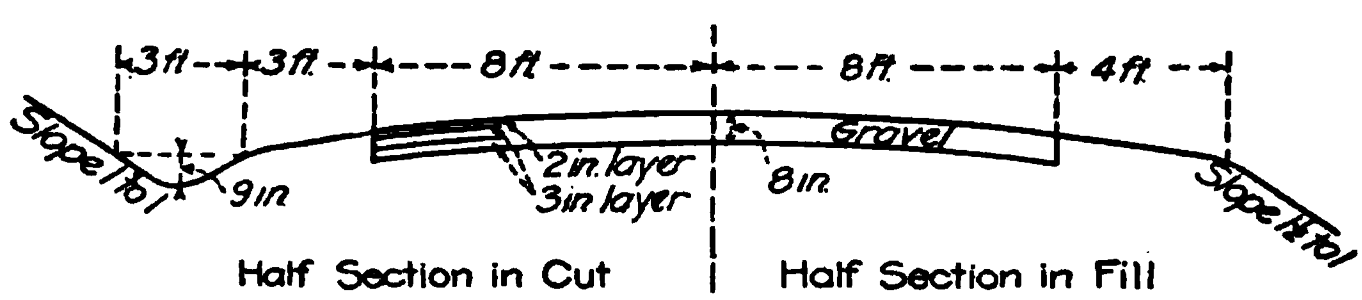


FIG. 41.—CONNECTICUT GRAVEL ROAD.

liable to break through the thin layer of gravel—particularly if a wet time intervenes. If the only gravel available contains an excess of large pebbles, they may be used in the lower layer, in which case the layer can not be compacted either by the wheels or by rolling. If the gravel is only slightly deficient in binding material, it will be impossible to use a *heavy* roller, since the gravel will push along in front of it.

Additional layers are added as rapidly as the preceding one is compacted, until the desired depth is reached. Before rolling the last layer, the earth at the sides of the trench, i. e., the "shoulders" or "wings," should be thoroughly rolled; and then the rolling of the gravel should proceed from the sides toward the center, to prevent the gravel from slipping outward. The gravel will compact much better when damp; but if it is sprinkled, care should be taken that (1) the gravel is not made so wet that the earthy binding material becomes semi-fluid and collects on the surface, and (2) that the subgrade is not unduly softened.

No practical amount of rolling will cause a gravel road to "come down" in the sense that a crushed-stone road does; that is, a gravel

road can not be rolled until the surface is as hard as it will probably be after it has been opened to traffic for a time, since even the heaviest rollers do not give as much pressure as the wheels of heavily loaded wagons. This difference between gravel and broken-stone roads is due to the fact that gravel has the binding material originally uniformly distributed throughout the mass, while with broken stone the binder is spread upon the top and worked in by rolling and sprinkling.

255. Surface vs. Trench Construction. Surface construction is cheaper and seems to be much more common than trench construction. Surface construction is the better, since the depth of the gravel at different distances from the center is approximately proportional to the amount of traffic; while in the trench construction, if the graveled portion is wide the sides are liable not to be much used, and if the graveled portion is narrow passing vehicles are forced upon the earth shoulders. Therefore it appears that surface construction is best for roads having a large amount of traffic. In park drives and streets, the whole width of the roadway is excavated and filled with gravel.

Trench construction is a little more economical of gravel, and is therefore most suitable where gravel is expensive.

256. Earth Road Beside the Graveled Way. It is sometimes advocated that there should be two tracks, an earth road for summer travel and a graveled way for winter use. This plan has some advantages and also some disadvantages. When the earth track is dry, it is preferred by most teamsters to the hard gravel road; and the use of the earth roadway decreases the wear on the gravel,—which is clearly an advantage, for a gravel road like most other things will wear out. On the other hand, if the summer track is immediately adjacent to the hardened way, the earth of the former will become mixed with the gravel of the latter, much to the detriment of the gravel. The chief source of expense in the maintenance of gravel roads is due to the damage done by the mixing of earth from the side of the road with the gravel, thus forming a mixture that will hold water and cause the road to cut up. It has been suggested that the objection to the two tracks could be obviated by constructing a ditch, or sodding a narrow space between the two; but this is impracticable. The two tracks

require a wider right of way, and therefore for this reason are frequently impossible.

257. BOTTOM COURSE. The gravel usually contains many stones too large to be used in or near the wearing surface, and therefore it is economy to screen the material and lay the larger pebbles in the bottom. Some writers object to using pebbles larger than 1 or 1½ inches in diameter for the bottom course, on the ground that the heaving effect of frost and the vibration due to the passing wheels will cause the larger stones to rise to the surface and the smaller ones to descend—"like the materials in a shaken sieve." Unquestionably, if a vehicle is driven over a layer of loose stones of all sizes, the larger ones will tilt up when the weight comes upon them and the smaller ones will roll down into the space made vacant by such tipping; and by a repetition of this process, the large stones will gradually reach the surface. The heaving action of the frost acts in a similar way. But it does not therefore follow that a layer of coarse stones at the bottom of a gravel road will thus work to the top when the interstices of the gravel above are filled with binding material and all is compacted by traffic or by rolling. Experience has shown that if 2 to 4 inches of the top dressing has suitable binding material, it is extremely improbable that pebbles 2 to 2½ inches in diameter in the bottom course will ever work to the surface.

258. Other materials than coarse pebbles may be used for the lower course. In many localities there are large quantities of coal slack, which is useless as fuel and is too friable for the wearing surface of a road, but which can be used for the bottom course of a gravel road. Coal slack has thus been successfully employed, and is often cheaper than gravel. Blast-furnace slag has also been used for this purpose. Sometimes broken stone is used for a bottom course; but on account of the expense of breaking, only a stone found already broken in the quarry is suitable for this purpose. A "flake" stone or quarry chips are the forms generally used. The celebrated gravel roads of Central Park, New York City, have a "rubble foundation"—not a Telford foundation (§ 302). The rubble layer is 10 to 12 inches thick, and the gravel 4 to 6 inches after being thoroughly compacted. The stones, none of which exceeded 9 inches in greatest dimensions, were dumped upon

the subgrade from carts and "evenly adjusted by a little labor of the hand." *

259. Screening the Gravel. As a rule gravel should be screened to exclude that which is too fine, and also to insure an even distribution of the fine and coarse material when placed upon the road. Where a small amount of gravel is required, the ordinary stationary inclined screen is used, the gravel being thrown against it with a shovel; but where a considerable amount is required, it is much cheaper to use a rotary screen driven by power. For the best results, three sizes of mesh should be used—2½ inch, 1½ inch, and ½ inch. The gravel which passes the first is to be used in the bottom; that which passes the second, in the middle course; and that which passes the third is used on top.

If the gravel contains a considerable quantity of stones more than 2½ inches in diameter, a stone crusher can be profitably employed, in which case it may be economical to use an elevator, rotary screen, and elevated storage bins, and to put all of the gravel through the crusher, rotary screen, and storage bin (see § 330).

Under favorable circumstances, the cost of screening by hand will be about 15 cents per cubic yard for each time the material is handled with a shovel; while with the rotary screen, it can be screened to three sizes and be placed in elevated bins for the same amount.

260. If the gravel must be put through the crusher, and suitable stone is available, a broken-stone road may be more economical than a gravel one.

261. Hauling the Gravel. Gravel is usually obtained from pits, and is generally overlaid with more or less earth, which should be entirely removed before beginning to haul the gravel. Not infrequently this earthy material is allowed to tumble into the pit and mix with the gravel, greatly to the detriment of the finished road.

The loading of the gravel can be greatly facilitated by using a board platform 8 to 10 feet long and 4 to 6 feet wide. This plat-

* W. H. Grant, Superintending Engineer, in Fifth Annual (1862) Report of the Board of Commissioners of Central Park, p. 67.

form is placed against the bottom of the bank in such a manner that when the gravel above is dislodged it falls upon the platform, from which it is easily shoveled into the wagon. Often the platform can be supported upon legs at a height above the top of the wagon, and the gravel can be simply pushed off into the wagon with the shovel. Sometimes the circumstances justify the use of a drag scraper (§ 137)—drawn by a horse attached to a cable passing through a block—to drag the gravel to the edge of the platform, whence it drops into the wagon; and sometimes, if a large quantity is to be loaded and a large number of teams are engaged in the hauling, the wagons can be loaded with a trap—an elevated platform upon which the gravel is hauled with a drag or a wheel scraper, and through which it drops into the wagon below.

262. MEASURING THE GRAVEL. When gravel roads are built by public officials, the gravel is usually measured in place in the pit or in the wagon. The former is the better practice, since it is more definite. When the road is built by contract, the gravel is measured (1) in the wagons, or (2) loose in the road by means of gage boards, or (3) compacted in the road by means of established grades. The first or second method is generally used with surface construction, and the third with trench construction. With the last, it is customary to require that the finished surface shall conform to an established grade, and consequently a considerable quantity of gravel is liable to be forced into the subgrade,—particularly if the earth foundation is made to conform to the grade established for it. The specifications for state-aid roads in New Jersey specify that "the contractor is to place sufficient gravel on the road to allow it to shrink 33 per cent in rolling and settling." * Loose gravel with clay or loam binder will shrink 12 to 15 per cent in rolling, and gravel in which the binder is produced by crushing part of the material will shrink still more—possibly twice as much; the above specifications provide, therefore, for the possibility of forcing 18 to 21 per cent of the gravel into the subgrade.

If it is expected that part of the gravel may be forced into the soil, the subgrade may be left a little higher than the established grade, and then the addition of the stipulated amount of gravel will

* Report of Commissioner of Public Roads, Trenton, N. J., 1900, p. 133.

bring the finished surface to the specified grade. Or, a thin layer of sand on the subgrade will sometimes prevent the gravel from being forced into the soil. For a further discussion of this subject, see § 335.

263. COST. The cost of gravel roads varies greatly with the form of construction, the cost of gravel, the amount of grading and drainage required, the width and thickness of the gravel, etc. An average depth of 1 foot over a width of 13½ feet requires half a cubic yard per linear foot of road, or 2,640 cubic yards per mile. The gravel usually costs from 5 to 10 cents per cubic yard in the bank stripped. The cost of loading will vary from 5 to 10 cents per cubic yard, not including the time lost by the team in waiting for a load. Setting gage plank, leveling, etc., may cost from 2 to 10 cents per cubic yard. The cost of hauling varies materially with the time of year (see § 4), and including the time lost in loading and unloading, will usually be at least 15 cents per cubic yard (about 1½ tons) per mile and seldom more than 30 cents—the former when done by farmers in the slack season and the latter when done by teamsters. For a haul of 1 mile the total cost in place is 40 to 50 cents per cubic yard.

264. Reports from forty-four counties in Indiana show that the total cost of construction of gravel roads in that state varies from $800 to $3,500 per mile; and except in a few counties, the cost varies from $1,000 to $2,500, and is generally from $1,000 to $2,000. The cost varies with the distance about as follows: when the gravel is hauled 1 mile, the total cost of the road is $1,000 per mile; when the haul is 2 miles, $1,250 per mile; when the haul is 3 miles, $1,500 per mile; when the haul is 4 miles, $1,750 per mile; and if 5 miles, $2,000 per mile. Numerous data from Ohio and Illinois seem to show that the above prices are fairly representative.

265. ECONOMIC VALUE OF A GRAVEL SURFACE. The value to a community of covering an earth road with gravel is a subject the discussion of which leads different persons to widely different conclusions, these depending upon the point of view and upon the data assumed.

The advantage of a gravel surface over one of earth is that the hard and impermeable surface of the former is equally good at all seasons of the year. The financial value of a road which is good at all

seasons of the year varies greatly with the locality and the occupation of those who use it. Near a large city such roads are nearly indispensable to dairymen, fruit growers, and truck farmers; but permanently hard roads are not of great financial advantage to grain growers and stock raisers, except in the immediate vicinity of a large city. A road which is uniformly good at all seasons of the year is of some economic advantage to a farming community, since it permits hauling to be done at times when other work is impossible, and since it makes possible the marketing of commodities when the price is most favorable. It is impossible to compute the money value of these factors; but, in general, it is not very great (see § 4–7). The chief advantage of a road good at all seasons of the year is its effect upon the social life of the rural district (§ 1–3).

The amount of a load that can be hauled on an earth road is often determined by the grades rather than by the nature of the surface; and unless the grades are light, the maximum load for a gravel road is not much greater than that for a dry earth road. Therefore, before adding a gravel surface to an earth road, the gradients should be carefully studied with a view of deriving the utmost benefit of the improved surface by securing easy ruling grades (see § 71).

It is well to remember that under certain conditions a gravel road is neither so firm nor so durable as a first-class crushed-stone road, but that the gravel road makes an excellent foundation for a subsequent surfacing of broken stone.

266. The cost of the improvement is the sum of (1) the annual interest on the cost of construction, (2) the excess of the annual cost of maintaining the gravel road over that of maintaining the earth road, and (3) the annual payment necessary to accumulate a fund sufficient to make periodic repairs, i. e., to add a new surface at intervals. The money spent in road improvements is to be considered as an investment which will return annual interest in the reduced cost of transportation and in the greater freedom of traffic and social intercourse.

267. GRAVEL VS. BROKEN-STONE ROADS. With the utmost care in construction, gravel will not make as smooth or as durable a road surface as first-class broken stone on account of the impossi-

bility of binding smooth water-worn pebbles as firmly as rough angular pieces of broken stone, and therefore gravel is unsuited for heavy traffic roads or streets, often being for these less economical than broken stone, owing to the greater expense of maintenance and repairs. On account of the low first cost of the gravel, and the fact that reasonably good gravel roads can be built without any investment of money in rollers, crushers, and other costly machinery, they are well suited to light traffic roads, to residence streets in small cities, and to park drives. Gravel is more suitable for park drives than broken stone because of its elasticity and its usually darker and less trying color.

ART. 3. MAINTENANCE.

268. Most of the instructions for the care of earth roads—Art. 2, Chapter III—apply also to gravel roads.

269. DESTRUCTIVE AGENTS. The destructive agents are the same for gravel as for earth roads (see § 187–93), except that for gravel roads a gradient is an element of destruction whose importance varies with its steepness. Horses in drawing a load up a hill or in holding back a load in coming down, are liable to displace pebbles with the calks of their shoes, and after the first stone is displaced it is easier to loosen others. The locking of the wheel, until it slides in going down hill, is also hard on a gravel or broken-stone road.

270. WORK OF MAINTENANCE. When a gravel road is first thrown open to traffic, it should be carefully watched and all incipient ruts and depressions should be filled as soon as formed, either by raking in gravel from the sides of the depression or by adding fresh gravel—in the earlier stages of this work the former is the better, and in the later stages the latter is necessary. The new gravel should be finer and contain more binding material than that employed in the original construction of the road. If the depression is very shallow, it is wise to roughen the surface with a garden rake before adding the new material. It is important that even ruts and shallow holes should be filled as soon as they appear, for they will hold water, which will soften the gravel bed and cause the road to wear rapidly. During this stage, all loose stones

should be removed from the roadway both for the comfort of travelers and the good of the road. At, say, every ½ mile a small pile of gravel should be stored to be used in filling depressions.

After the gravel has become thoroughly consolidated, i. e., after the wheels no longer make even shallow ruts, the only care the road is likely to need for several years is to keep the side ditches and culverts free from weeds and floating trash, and to attend to the drainage of the surface when the snow is melting (§ 214).

After a time the gravel will work out to the sides of the road too far, and the center will wear hollow. It will then be necessary to use a scraping grader (§ 142–43) to push the gravel back to the center. In doing this care should be taken not to scrape up the earth with the gravel. A good time to use the grader is just after a rain, when the road is soft and easily scraped, and when the gravel scraped to the center is in the best condition to pack again. The road should never be allowed to wear so hollow in the center as to interfere with the flow of water from the surface to the side ditches.

271. REPAIRS. It will finally be necessary to repair the surface by adding a coating of new gravel. For this purpose the size of the largest pebbles should vary with the thickness of the coat. It is usual to put the gravel on by making two or three dumps of a wagon load, i. e., by stretching a cubic yard over 15 to 25 feet, according to the thickness of layer required, and spreading the gravel just a little wider than the wagon track. Traffic will spread it still wider, and also pack it.

In making repairs, it is better to apply a thin coat often than a thicker coat less frequently, since a thick coating does not pack well. A layer of 2 inches of gravel is better than more—unless on a spot that has cut through.

272. SPRINKLING. A gravel road with clay binder needs a little moisture to hold it together, since the clay shrinks and cracks under excessive drought, loses its binding power, and permits the road to break to pieces. Under such circumstances a sprinkling with water is a means of preserving the road from serious damage, although on account of the expense this is seldom done except on park drives.

The cost of sprinkling the drives and walks in Boston parks in

1891 was 2.4 cents per square yard per annum, of which one quarter to one third was for water and the remainder for teaming and labor.*

273. COST. The cost of maintenance varies with the climate, the amount and nature of the traffic, the quality of the gravel, etc. Data from Indiana and Ohio show that it varies from $40 to $100 per mile per annum—the former where the traffic is light, the gravel good, and the snow light; and the latter where the traffic is heavy, the gravel poor, and the snow heavy.

* Journal of Associated Engineering Societies, Vol. 11, p. 441.

CHAPTER V.

BROKEN-STONE ROADS.

274. A broken-stone road is one built by placing small fragments of stone on the ground and compacting them into a solid mass. Such a road is frequently called a macadam road after John Loudon MacAdam (1756–1836), a famous English builder of broken-stone roads. The broken stone is often called macadam, and the work of construction macadamizing. Small fragments of broken stone have been used as a road surface from time immemorial, and a first-class modern broken-stone road differs in several essentials from the form advocated by MacAdam, as will appear later in this chapter (see § 302–04, § 331, and § 336); and therefore the term macadam is not altogether appropriate as a synonym for a broken-stone road. Strictly speaking it should be used only to designate the foundation or lower course of a stone road composed entirely of small fragments (§ 302).

A broken-stone road is sometimes called a telford road after Thomas Telford (1757–1834), a famous English engineer; but the term telford is usually, and appropriately, restricted to a particular form of the foundation of a broken-stone road (see § 302).

Art. 1. The Stone.

275. Requisites for Road Stone. The principal requisites of a material for a broken-stone road are hardness, toughness, cementing or binding power, and resistance to the weather. Usually any stone that is hard and tough will resist the weather reasonably well; but shales and slates, though hard and tough when first quarried, often disintegrate when exposed to the weather. The material for a road surface should also be uniform in quality

or the surface will wear unevenly, and the depressions which occur where the materially is comparatively soft will hold water, thus softening the road-bed and occasioning damage difficult to repair.

276. Hardness and Toughness. These two qualities are closely related. Hardness is that property of a solid which renders it difficult to displace its parts among themselves; while toughness enables the parts to yield somewhat without being separated or broken. For road purposes, hardness is the power possessed by a rock to resist the rubbing or the abrasive action of wheels and horses' feet; while toughness is the adhesion between particles of a rock which gives it power to resist fracture when subjected to the blows of traffic. A stone may be hard and brittle, and be quickly pounded to pieces in the road, as quartz; or it may have a high crushing strength and yet be deficient in toughness, and grind away speedily under the abrasion of traffic, as some varieties of sandstones. A road metal should have enough resistance to crushing to support the load brought upon it by the wheels, and enough toughness to prevent its being readily ground into powder. A large part of the fine material is inevitably swept away by the rains and winds, or is removed by scrapers to keep the road in good condition during wet weather; and therefore it is important that the fragments should be tough enough not to be unduly pulverized by the traffic. Toughness is incompatible with a high degree of hardness, and in a measure makes up for a deficiency in resistance to crushing. Hardness could be measured by the resistance offered by a rock to the grinding of an emery wheel; and toughness would be measured by the resistance to fracture when struck with a hammer.

277. Cementing or Binding Power. Binding power is the property possessed by rock dust to act as a cement between the coarser fragments composing a stone road. This property is of the highest value, for the strength of the binder determines the resistance of the road to the wear and tear of traffic more than does the strength of the fragments themselves. It is possessed in a very much higher degree by some varieties of rocks than by others, and its absence is so pronounced in some varieties that they can not be made to compact under the roller or under traffic without the addition of some cementing agent. This subject has been studied

but little, and only by the Massachusetts Highway Commission, which offers the following tentative conclusions:*

"It is difficult to say what brings about this cementation or binding of rock dust. It is clear, however, that with many varieties of rock it is due to several causes. Experiments made on a number of different kinds of rock dust showed that the more finely they were pulverized the higher would be the cementing value when subjected to pressure, both with and without water; and an increase in pressure seems to produce a corresponding increase in cementation. Further than this, in a number of cases similarly made briquettes of the same rock dust gave distinct indication that destruction to the bond of cementation by impact bore a definite relation to the amount of energy expended; i. e., about the same amount of energy was required to destroy the bond in each briquette, even when applied in different loads. The inference drawn from such results would be that cementation in such materials is to a considerable extent mechanical,—that is, the interlocking of the fine particles of dust caused by pressure.

"Another important fact brought out was, that every variety of rock experimented on gave higher cementing results when compressed while wet, which is analogous to the results obtained by road builders, who almost invariably find that stone screenings compact better when watered before being rolled. This at first led to the belief that this result was entirely due to a chemical change effected by the water; but briquettes made of pulverized glass, mixed with pure alcohol instead of water, gave practically the same results. The only explanation of this fact which at present suggests itself is that any mobile liquid which will wet the fine particles of dust acts as a lubricant, allowing them to come in close contact when under pressure.

"By a process little understood, water has the power of attracting the fine particles of rock dust and cementing them together. This is well illustrated when a drop of water falls on a dry hard road surface by the dust immediately buckling into an irregular shape, which is retained until destroyed by some force. On examining one of these little clods after drying, it will be seen that it

* Annual Report for 1900, p. 71-2.

sensibly coheres. The solidifying of mud by the drying up of puddles of water on clayey soil is another example, and so this same process can be traced even to the clay concretions. These phenomena may be due to totally different causes; nevertheless each is the cementation of rock dust, brought about by the presence of water, and in each case the finer the dust the more perfect this action. This cementation may be due to chemical action, to physical re-arrangement of the particles, or more likely to a combination of such causes."

278. Although chemical action does not seem to affect the cementing power of stone dust as determined in the laboratory, it is probable that this force plays an important part in the road itself. Many native rocks consist of small bits bound together by a cementing material which was deposited from the water. Pure water will dissolve several of the common constituents of rocks, and its solvent action is materially increased by the acids which it takes up from the atmosphere and from manure and decaying vegetation on the road surface. Water percolating through the road material will dissolve lime, silica, and iron,—common cementing materials in natural rock,—and later deposits them in the interstices of the crushed stone, where they will act as a binding material. This binding action is quite slight, but may have an appreciable effect in maintaining the delicate adjustment of a broken-stone road. This subject has not been investigated, but it is apparently worthy of careful study.

279. METHOD OF TESTING STONE. There are two methods of determining the qualities of a stone for road-building purposes: (1) by using the stone in the road and keeping an account of the cost of repairs over a series of years, or (2) by laboratory experiments. The first is uncertain owing to the variations in climatic conditions, and in the amount and nature of the traffic, etc., and would be very expensive and take a long time. In the second method of testing, it is difficult to duplicate in the laboratory the conditions of actual service; but nevertheless much valuable information may thus be obtained at a moderate expense and in a comparatively short time.

The first method of testing road-building stones will be considered in Art. 3—Maintenance.

Systematic laboratory tests of road metal are of comparatively recent origin, and may be said to have been started by the French governmental engineers about 1880, who have made extensive use of this method in determining the quality of the rock used in contract work and in selecting new quarries. Only a little such laboratory work has been done in England and Germany. From 1894 to 1899 the Massachusetts Highway Commission conducted a series of tests of road-making materials, and developed a new and important method of testing, and deduced much valuable information.

280. Abrasion Test. This test determines the toughness of a stone, and is employed principally by the French engineers, who use the machine shown in Fig. 42.*

"The specimens to be tested are sawed into rectangular prisms having a 4 cm. (1.6 inches) by 6 cm. (2.4 inches) base, and an 8 cm. (3.2 inches) height. These specimens are placed, two at a time, so that they rest on the upper surface of a circular grinding disk of cast iron, which can be rotated in a horizontal plane by a crank. They are held in clamps so arranged that the bases of the specimens rest on opposite sides of the grinding surface, 26 cm. (10.4 inches) from the center. The specimens are weighted so that they press against the grinding disk with a pressure of 250 grammes (8.8 ounces) per square centimeter (0.4 inch). Sand is fed onto the disk from a funnel above. The sand used is of a standard quality and size, obtained by crushing quartzite rock and screening it to the standard size. The quantity of sand used in each test is one litre per specimen for each thousand turns of the grinding disk. The disk is rotated at the rate of 1,000 revolutions per half hour, and a test is completed in 4,000 revolutions. The diminution in the height of the specimen is measured, and its loss in weight determined after each 1,000 turns of the disk. The per cent of loss undergone by each specimen after 4,000 revolutions of the grinding disk is set down as the result of the test, and serves for comparison."†

281. Impact Test. The French engineers test the ability of a stone to resist impact, by means of a machine which resembles

* Report of Massachusetts Highway Commission for 1900, p. 76.

† *Ibid.*

very closely in principle the pile driver. The hammer is raised by a cord which passes over a pulley at the top of the guides and can be released at any desired height, from which it falls upon the specimen, which is held below by clamps. Two hammers are employed, one weighing 42 kilogrammes (92.4 pounds) and the other 20 kilogrammes (44 pounds), their respective falls being 100 cm. (40 inches) and 80 cm. (32 inches). The number of

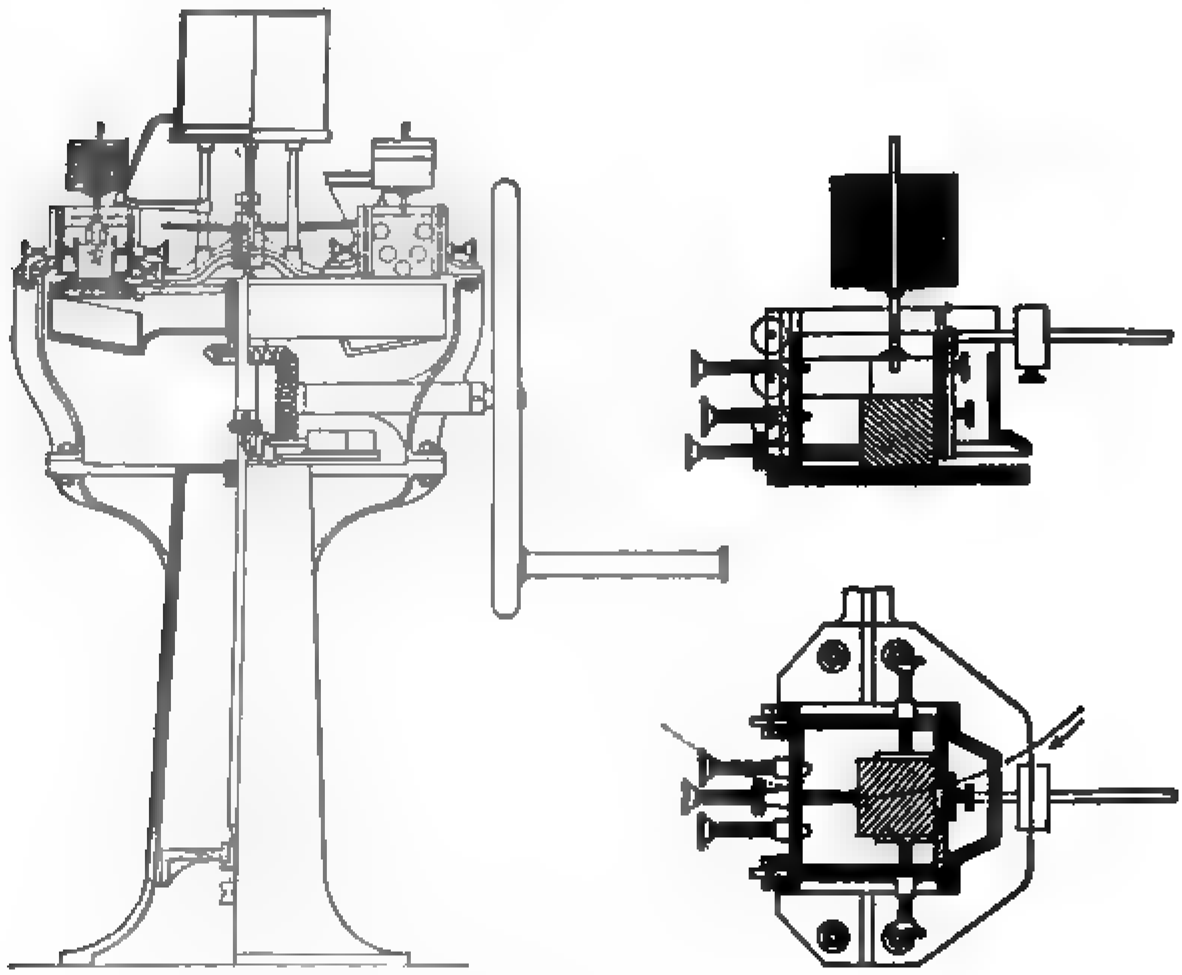


FIG. 42.—DORRY ABRASION TESTING MACHINE.

blows necessary to crack the specimen and also the number to produce its complete destruction are determined. The test is made upon 4-cm. cubes, at least three cubes being used for each specimen with each hammer.

This and the preceding test will not be further considered here, since the resistance to impact and abrasion are more easily determined by the method immediately following.

282. Abrasion and Impact Test. This test consists in placing a known weight of fragments in a tight drum which rotates about an eccentric axis so that the bits roll over one another and also

shift from end to end in the cylinder. This test was invented by Deval, a French engineer, and has been widely used. It determines at once the resistance to abrasion and also to impact, and is an important test for road metal. Fig. 43 shows the form of the Deval machine used in this test by the Massachusetts Highway Commission.*

"The machine consists of four cylinders, each 20 cm. (7.9 inches) in diameter and 34 cm. (13.4 inches) in depth. Each of these cylinders is closed at one end and has a tightly fitting cover for

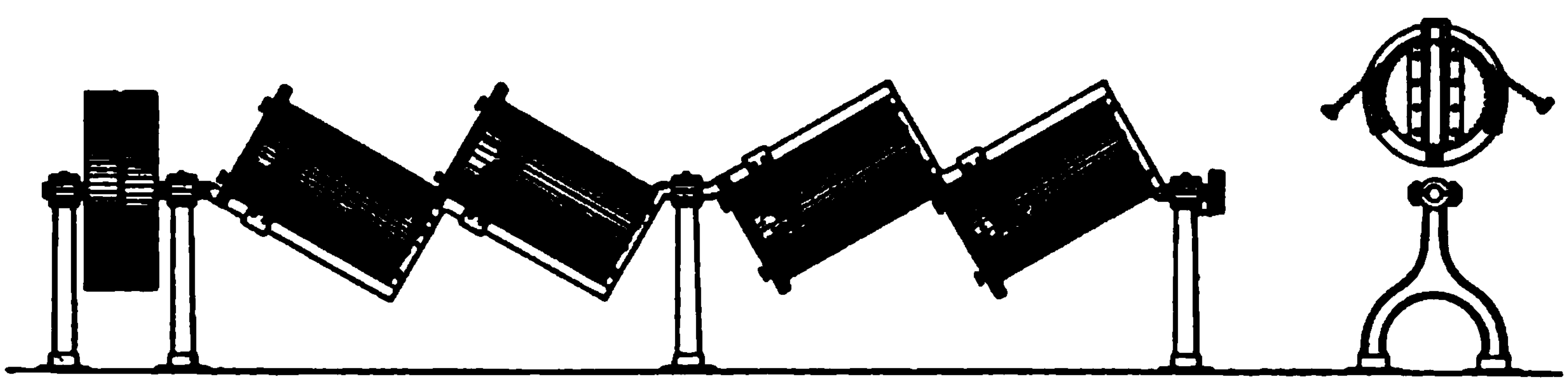


FIG. 43.—DEVAL IMPACT AND ABRASION TESTING MACHINE.

the other. They are fastened to a shaft so that the axis of each cylinder is at an angle of 30° with the axis of rotation of the shaft. The shaft which holds the cylinders is supported by bearings; and at one of its ends is a pulley by which the cylinders are revolved, and at the other a revolution counter.

"The stones employed in making the abrasion test are about the size used in making macadam roads—between 6.31 cm. (2.5 inches) and 3.18 cm. (1.25 inches) in diameter. In making a test 5 kilogrammes (11 pounds) of perfectly clean stone of the above dimensions are placed in one of the cylinders; the cover is then bolted on, and the cylinder rotated at the rate of 2,000 revolutions per hour for five hours. Four tests can be made at once by using all four cylinders. At each revolution of the shaft the fragments of stone are thrown twice from one end of the cylinder to the other, which grinds them against one another and against the walls of the cylinder. After 10,000 revolutions the machine is stopped, the cylinder opened, and the contents placed on a sieve having 0.16 cm. ($\frac{1}{16}$ inch) meshes. The material that passes through the sieve is put aside for the cementation test. The sieve and the remaining fragments of stone are then held under running

* Annual Report for 1900, p. 80.

water until all the adhering dust is washed off. After these remaining fragments have thoroughly dried they are carefully weighed, and their weight is subtracted from 5 kilogrammes (11 pounds)—the original weight of all the stone in the test. The difference obtained is the weight of the detritus under 0.16 cm. ($\frac{1}{16}$ inch) worn off by the test."

The relative resistance of stones in the abrasion test is expressed either (1) by the Per Cent of Wear, i. e., by the ratio of the weight of the dust worn off to the original weight of the stone, or (2) by the Co-efficient of Wear adopted by the National School of Roads and Bridges of France. The latter is represented by the formula:

$$\text{Co-efficient of Wear} = 20 \times \frac{20}{w} = \frac{400}{w},$$

in which w is the weight in grammes of detritus under 0.16 cm. ($\frac{1}{16}$ inch) in size obtained per kilogramme (2.2 pounds) of stone. The French road engineers usually regard a co-efficient of 20 as indicating a stone excellent for road purposes, and one of 10 as sufficiently good. The larger the Co-efficient of Wear the better the stone; while a small Per Cent of Wear indicates a good stone. The Per Cent of Wear is equal to forty divided by the Co-efficient of Wear; and vice versa, the latter is equal to forty divided by the former.

Table 19, page 186, gives the Per Cent of Wear obtained by the Massachusetts Highway Commission; and Table 20, page 187, gives similar results obtained under the auspices of the U. S. Agricultural Department—in both cases under the direction of Mr. Logan Waller Page. In Table 20 the Per Cent of Wear is the total percentage of all material less than 1¼ inches, while the French Co-efficient of Wear is based upon the percentage of material less than $\frac{1}{16}$ inch in diameter; and therefore in Table 20 these results are not related as stated in the preceding paragraph.

In 1901 the U. S. Road Material Laboratory introduced a new term to express the quality of a road-building material, but called it Co-efficient of Wear. In Table 18 this new term is designated Co-efficient of Wear (U. S. A. D.), the initials in the parenthesis standing for U. S. Agricultural Department, and distinguishes this Co-efficient from the similar French Co-efficient. The

U. S. A. D. Co-efficient is obtained as follows: Subtract 4,000 from the weight of the abraded material larger than 1¼ inches, and divide the difference by 10. If no wear takes place, the Co-efficient will be 100; and if there is 20 per cent of detritus smaller than 1¼ inches, the Co-efficient will be 0, and the material is considered unfit for road making. "This term was introduced to secure a result with more range to it and one that could be more easily understood by the average layman." The innovation is of doubtful propriety.

283. Cementation Test. This test was invented by Mr. Logan Waller Page, Geologist of the Massachusetts Highway Commission, and was developed during the years 1896 to 1899. The test is made by wetting the stone dust with water, and molding it into a short cylinder, which after being dried is subjected to the blows of a dropping weight.

"To make the test specimen, the dust of rock that is to be tested is passed through a screen having 40 meshes per cm. (100 per inch), and is obtained from the detritus of the abrasion and impact test. The dust is made into briquettes of circular sections, 25 mm. (0.98 inch) in diameter and 25 mm. in height, by placing the dust in a metal die of the proper dimensions, with enough distilled water to moisten it (4 cc. or 0.24 cubic inches); a closely fitting plug is then inserted on top of the wet dust, and it is subjected to a pressure of 100 kgs. per sq. cm. (1,422 pounds per square inch). The weight of the dust varies with the density and compressibility of the stone, but generally it requires about 25 grs. (0.9 ounce) of dust to make a briquette of the above dimensions. Two weeks should be allowed for a briquette to dry, at the ordinary temperature of a room, after which it should be tested within a few days.

"Fig. 44, page 188, shows the machine employed in testing the specimen. The machine consists of a 1-kilogramme (2.2-pound) hammer, *H*, arranged like the hammer of a pile-driver on two vertical guides, *D*. The hammer is raised by a screw, *C*, and dropped automatically from any desired height. It falls on a flat-end plunger, *B*, weighing 1 kilogramme, which is pressed upon the briquette, *O*, by two light spiral springs held by the guide rods, *F*. The plunger, *B*, is bolted to a cross-head, *G*, which is guided by

TABLE 19.

TESTS OF STONE TO DETERMINE ITS ROAD-BUILDING QUALITIES.

Compiled from the Reports of the Massachusetts Highway Commission, 1896–1901.

Ref. No.	Name of Stone.		Impact and Abrasion Test.					Cementing Value			Weight, Lb. per Cu. Ft.	Water Absorbed, Lb. per Cu. Ft.
	Common.	Scientific.	No. of Samples.	Per Cent of Wear.‡			Mean Co-efficient ‡ (French).	Max	Min.	Mean		
				Max.	Min.	Mean.*						
1	Trap	Basalt	3	2.15	1.31	1.65	25.31	31	16	23.5	187	0.14
2	"	Diabase	33	4.31	1.31	2.21	18.25	62	13	29.4	184	0.19
3	"	Diabase porphyry	5	2.72	1.81	2.21	18.68	......	17	......	182	0.12
4	"	Unidentified	15	4.48	1.52	2.46	17.71	53	18	30.6	185	0.22
5	"	Hornblende syenite	3	3.17	2.07	2.53	16.43	......	11	......	181	0.12
6	Porphyry	Felsite	9	3.25	2.01	2.77	14.92	101	16	42.6	167	0.19
7	Sandstone	Sandstone	9	4.18	1.71	2.87	15.01	20	10	13.2	170	0.61
8	"	Quartzite	5	4.41	1.97	3.19	13.47	......	14	......	166	0.18
9	Granite	Hornblende granitite	17	4.64	1.90	3.03	14.28	77	8	23.4	175	0.20
10	"	Granite	9	4.76	2.23	3.50	12.11	14	5	8.8	166	0.22
11	"	Gneiss	14	7.98	1.73	4.34	10.55	28	1	12.6	172	0.17
12	"	Gabbro	1	......	......	5.36	7.46	......	12	......	185	0.71
13	Field stones	Coarse drift material	82	8.22	2.08	4.12	10.70	46	5	16.6	......	......
14	Limestone	Limestone	12	6.34	2.10	4.04	10.14	26	8	16.0	170	0.26
15	"	From State of N. Y.†	9	6.45	2.90	4.69	9.08	94	15	53.7	......	......
16	Schist	Schist	7	8.20	3.27	4.28	10.24	......	16	......	178	0.11
17	Gravel	Crushed gravel	1	......	......	3.01	13.24	......	10	......	......	......
18	Slate	Cambrian slate	1	......	......	4.72	8.48	......	......	......	......	......
19	Flint	Chert	1	......	......	4.79	8.35	......	......	......	......	......
20	Marble	Marble	1	......	......	14.01	2.85	......	......	......	......	......

* The per cent of wear is equal to 40 divided by the co-efficient of wear (see § 282); but for reasons too complicated to explain here the means of these two quantities are not thus related.

† See Report of N. Y. State Engineer, 1900, p. 15–18.

‡ Detritus $\frac{1}{16}$-inch or less.

TABLE 20.

TESTS OF STONE TO DETERMINE ITS ROAD-BUILDING QUALITIES.

Results obtained in the Road-material Laboratory of the U. S. Department of Agriculture in 1900–01.

Ref. No.	Scientific Name of the Stone.	Impact and Abrasion Test. No. of Samples.	U. S. A. D. Per Cent of Wear.* Max.	U. S. A. D. Per Cent of Wear.* Min.	U. S. A. D. Per Cent of Wear.* Mean.	Mean Co-efficient. French.†	Mean Co-efficient. U. S. A. D.*	Cementing Value. Max.	Cementing Value. Min.	Cementing Value. Mean.	Weight, Lb. per Cu. Ft.	Water Absorbed, Lb. per Cu. Ft.
1	Andesite	1	......	6.0	......	11.5	70.0	......	35	......	162	1.9
2	Chert	13	4.7	23.3	19.60	4.27	22.0	148	2	35.2	112	3.2
3	Clay	3	......	20.1	......	2.1	0	3 059	45	2 296.5	......	......
4	Conglomerate	2	18.7	14.2	16.45	5.1	17.6	327	124	225.5	156	3.15
5	Diabase	12	12.1	1.7	3.73	16.16	81.4	110	2	39.0	187	0.33
6	Diorite	4	10.4	2.7	5.40	10.85	73.0	337	3	129.5	173	1.22
7	Dolomite	4	13.1	4.8	8.48	6.10	57.7	161	14	56.0	169	0.7
8	Felsite	1	......	4.5	......	11.9	77.4	......	12	......	156	0.31
9	Flint	2	9.8	6.1	7.95	6.2	60.3	31	17	24.0	161	0.75
10	Gabbro	1	......	2.9	......	14.3	85.3	......	131	......	184	0.1
11	Gneiss	6	7.0	3.3	4.83	9.98	75.9	49	8	24.2	161	0.33
12	Granite	13	10.6	1.9	5.22	11.65	77.0	39	2	8.7	166	0.23
13	Gravel	12	......	......	......	......	......	249	9	56.7	......	......
14	Limestone	33	35.2	3.1	10.28	6.51	55.5	231	8	85.4	166	1.66
15	Marble	1	......	4.1	......	10.1	79.5	......	90	......	166	1.
16	Minetta	1	......	6.4	......	12.5	68.2	......	18	......	169	1.
17	Novaculite	1	......	20.0	......	6.8	0	......	12	......	154	3.3
18	Quartzite	2	4.3	3.1	3.70	12.85	81.6	2	2	2.0	173	0.15
19	Rhyolite	2	23.0	10.3	16.15	4.26	24.2	577	513	545.0	166	3.55
20	Sandstone	6	33.8	4.3	15.40	5.80	40.1	323	13	84.7	154	5.52
21	Schist	2	6.0	4.5	5.25	8.5	73.7	36	6	21.0	192	0.3
22	Shale	2	44.9	5.8	25.35	5.55	35.4	380	62	221.0	168	1.65
23	Slag	2	32.3	9.3	20.80	5.00	26.8	137	19	78.0	154	2.1
24	Slate	2	10.8	5.0	7.90	7.15	60.4	202	151	176.5	172	0.45
25	Trachyte	2	2.4	1.9	21.50	20.9	89.2	24	9	16.5	179	0.25

* Detritus $1\frac{1}{2}$-inch or less. † Detritus $\frac{1}{16}$-inch or less.

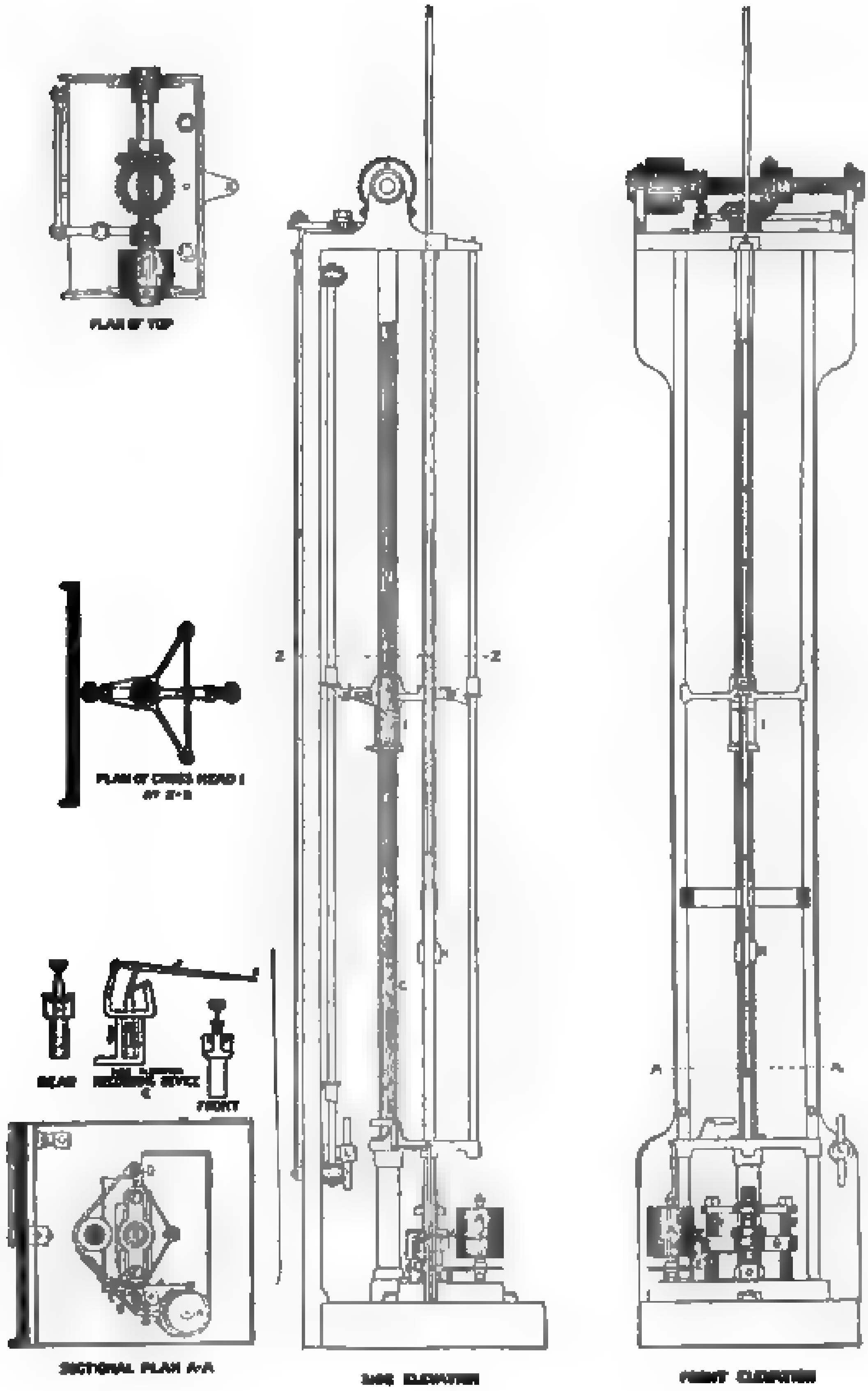


Fig. 44.—Impact Machine for Testing Cementation.

two vertical rods, *F*. A small lever, *J*, carrying a brass pencil, *K*, at its free end, is connected to the side of the cross-head by a link motion, arranged so that it gives a vertical movement to the pencil six times as great as the movement of the cross-head. The pencil is pressed against a drum, *A*, and its movement is recorded on a slip of paper fastened thereon. The drum is moved automatically through a small angle at each stroke of the hammer; and thus a record is obtained of the movement of the hammer after each blow. The standard fall of the hammer for a test is 1 cm. (0.39 inch), and the blow is repeated until the bond of cementation of the material is destroyed. The final blow is easily ascertained, for when the hammer falls on the plunger, if the material beneath it can withstand the blow, the plunger re-bounds; if not, the plunger stays at the point to which it is driven, which is clearly recorded on the slip of paper. The number of blows required to break the bond of cementation is taken as representing the binding power of the stone." *

Table 19, page 186, shows the results obtained under the auspices of the Massachusetts Highway Commission; and Table 20, page 187, gives similar results obtained in the Road-material Laboratory of the U. S. Department of Agriculture—in both cases under the immediate direction of Mr. Page, the inventor of this method of testing road metal. This test was not applied to as many specimens as the Impact and Abrasion Test.

284. Crushing Test. This test in a degree determines the hardness of a stone; but it is seldom applied to determine the suitability of a material for road metal, since hardness is more easily determined by the impact and abrasion test (§ 283). For detailed instructions as to the method of making the crushing test, see the author's Treatise on Masonry Construction.

285. Absorption Test. The method employed by the Massachusetts Highway Commission in making this test is as follows: A smooth stone, between 20 and 60 grammes in weight, that has been through the abrasion and impact test is weighed in air. It is then immersed in water, and immediately re-weighed in the water. Experiments having shown that absorption practically

* Report of Massachusetts Highway Commission, 1900, p. 80–81.

ceased after 62 hours, it was concluded that an immersion of 96 hours would be a safe allowance. After 96 hours of immersion the stone is again weighed in water. The absorption is then computed by the formula:

$$\text{Number of pounds of water absorbed by a cubic foot of rock} = \frac{C - B}{A - B} \times 62.5,$$

in which A is the weight in air, B the weight immediately after the immersion in water, C the weight after absorption for ninety-six hours, and 62.5 the weight of a cubic foot of water.

Table 19, page 186, shows the results obtained by the Massachusetts Highway Commission, and Table 20, page 187, gives similar results by the U. S. Department of Agriculture.

286. The absorptive power of the stone is tested to determine the probable effect of frost upon the material. It is well known that water in freezing exerts a considerable expansive force; but this does not prove that freezing will seriously injure a road material that absorbs water even to a considerable amount. The absorptive power depends upon the porosity, and when a porous stone is immersed in water its pores are filled with air, which the water does not entirely drive out; and this air serves as a cushion to take up the expansion of the water in freezing. For this reason, freezing does little or no injury to stone or brick which are otherwise suitable for road purposes. A rock or brick so porous as to be damaged by freezing while wet, would probably be rejected by a casual inspection—certainly by the tests ordinarily applied.

287. Characteristics and Distribution of Road-building Rocks. Experience in France and Massachusetts has shown that the results of the impact and abrasion test agree reasonably well with the relative values of the stones as determined by actual wear in the road. The different stones are arranged in Table 17 substantially in the order of their wear in the impact and abrasion test, and consequently this order represents approximately the relative value of the several stones for road-building purposes. However there are some exceptions to this order. Where the traffic is light a hard stone may not furnish enough dust to replace that blown away by the wind and washed away by the water, and also to bind the surface; and in such case a softer stone or one with a higher cementing power may be preferable. A suitable

road stone should be soft enough to grind to dust only slowly under the traffic, and this dust should have a high cementing power, and the separate fragments of the stone should have strength enough to resist the crushing action of the wheels.

The characteristics and distribution of the road-building materials which are extensively available will now be briefly considered.

288. Trap. This is a popular term applied to any dark-colored, massive, igneous rock. Trap is very compact and elastic, has a high resistance to crushing without being brittle, and its dust has the cementing power in a high degree. The different traps are not uniformly desirable, but nearly all of them are better than the best of other rocks; and therefore the traps may clearly be placed first in order of utility among road-building stones.

289. Trappean rocks are plentiful in the greater part of New England, in the upland districts of New Jersey and the neighboring portions of Maryland and Pennsylvania, in the Blue Ridge mountains between the Potomac and the James rivers, in the basin of Lake Superior, particularly in the northern peninsula of Michigan, and in the Rocky mountains. They are also found to a limited extent in southern Missouri, in Arkansas, and in central Texas.* In America the trap rocks are not as plentiful nor as evenly distributed as in Europe.

The traps of Table 19, page 186, include eight samples from New Jersey, two from New York, two from Connecticut, and one from Rhode Island, the remainder, forty-six, being from Massachusetts.

290. Granite. Next in value to the trappean rocks are those commonly called granites. These are massive granular rocks composed essentially of quartz and feldspar, but almost always containing mica, hornblende, and other components. An essential feature of granite is an evenly granular structure coarse enough to be distinctly visible to the naked eye. Granites vary widely, but as a rule they are inferior road material owing to the brittleness of both the quartz and the feldspar, and also to their coarsely granular structure. If the quartz is absent. the rock is what is technically called syenite, the best for road metal of the so-called

* Shaler's American Highways, p. 56–58.

granites. When granite is free from mica, it offers great resistance to wear. If the granitic rock has a pronounced fibrous or hairy arrangement of its mineral constituents, the rock is termed gneiss, most samples of which are very inferior road materials.

The feldspar of granite is readily decomposed, producing sand and clay; and when this change has gone on to a considerable degree, the stone should be discarded as unfit for road material, since it readily crumbles to sand and clay under the action of frost and traffic, and the wind sweeps away the fine material in dry weather, and in rainy times the road is in a muddy state. For this reason, granite is more satisfactory in southern than in northern localities.

291. "The distribution of the granite rocks is unfortunately in a general way the same as that of the trappean rocks (§ 289). Between the traps and the granites about one third of the area of the United States is fairly well provided with road-making stones." *

292. Limestone. The limestones are usually deficient in hardness and toughness, but possess cementing power in a fair degree (see Tables 19 and 20). Limestones where found in thin layers with little sign of crystallization, particularly where they contain a small amount of clay,—say, not more than twenty-five per cent,—often afford tolerable road stones. In proportion as limestone becomes crystalline, i. e., takes on the character of marble, its value in road-making diminishes, for the reason that the crystalline structure in most cases so far weakens the mass that it is apt readily to pass into the state of powder. Marble has a high per cent of wear and a low cementing power—see Table 19. Marbles occur only in districts where better road-making materials are likely to be present.

It should not be forgotten that the limestones in Tables 19 and 20 are selected samples and are not representative of the whole series. Some limestones are entirely too soft for road material.

293. The limestones are the most widely diffused of any bedded rock employed for road purposes. In a large part of the Mississippi Valley, they constitute the only material, except glacial drift, with which to build broken-stone roads.

* Shaler's American Highways, p. 58–59.

294. Sandstones. As a rule sandstones are worthless as road-making materials, being deficient in binding power and easily reducing to sand. Notice that while the resistance of sandstone to abrasion and impact entitles it to a high place in Table 19, it is very low in cementing power. Occasionally samples are found which have sufficient binding material between the grains to hold the mass firmly together in such a manner as to render it a fair road-building material.

Quartzite was originally sand, and has been changed into a compact mass by pressure and heat. The quartzites differ greatly, but are generally too soft or have too little cementing power to make a good road-building material. They are confined to comparatively "limited areas, being found principally in the mountainous districts of the Appalachian and Cordilleran areas and in the Adirondacks and the Ozarks." *

Quartz when found in large veins sometimes makes a fair road metal. It is very hard and breaks with sharp edges, but readily crushes into fine dust which has no binding power. Roads of this material rarely attain a smooth surface and always wear very rapidly.

295. Chert, a variety of quartz, is a siliceous material with the characteristics of flint, but differing from it in being of a tougher nature, and in breaking with a splintery instead of a conchoidal fracture. Chert has a variety of colors—red, yellow, gray, and brown. It is usually mixed with more or less lime, and beds of chert often grade imperceptibly into limestone. Chert varies greatly in quality, and being brittle and somewhat deficient in binding power it is never a first-class road stone, but will usually give fairly good results. It is often of great value, since it occurs in those parts of the country where good road-building material is scarce or entirely absent. Chert is not usually found in a solid mass, but in a finely divided state, broken ready for placing upon the road. Chert has already been considered as a gravel (see § 239).

296. Field Stones. In the glaciated district (see § 238), an excellent road material may be obtained by crushing the bowlders and pebbles that are too coarse for use in gravel roads.

*Shaler's American Highways, p. 59.

"Where the glacial bowlders have lain since the ice time exposed to the weather, or where, being of small size, they lie in the zone to which decay has penetrated from the surface, they are often so far decomposed as to be essentially unfit for use in road-making, save it may be as telford pavement, or as a bottom coating of broken stone which is to be covered with material of a better grade. The variation in the extent to which decay has injuriously affected the surface stone may be judged by simple tests which may be readily applied. After a brief experience a judicious person with a light sledge hammer can, by striking the stones, readily determine the state of the masses. If they ring sharply to the blow they may be judged sufficiently sound. If, however, they pulverize under the successive strokes, or if they show evident traces of decay, as by iron stains penetrating the mass, they may be condemned as a source of supply." *

There is inevitably a good deal of difference in the road material obtained from bowlders and pebbles, and care should be taken not to mix the hard and soft varieties, as otherwise the road will wear unevenly. If the different varieties are laid in distinct sections, valuable knowledge may thus be obtained as to the wearing qualities of the different grades.

297. Felsite. This is a hard flinty rock having about the same chemical composition as granite, but which to the unaided eye appears homogeneous. It is frequently classed as a granite. Notice that felsite is particularly high in cementing power—see Table 19.

It is found in large quantities in eastern Massachusetts, and to some extent in New Hampshire, Maine, Pennsylvania, Missouri, Minnesota, and Wisconsin.

298. Shale and Slate. These are both indurated or hardened clay. These terms are often used synonymously; but shale is less compact than slate, and will not split into slabs and sheets as does slate.

Shale is the most abundant of all stratified rocks. When the clay is nearly pure it is called argillaceous or clay shale; and when it contains considerable sand, it is known as arenaceous or sandy

* Shaler's American Highways, p. 69.

shale. The shales vary in color, being gray, reddish, or very black. For road-building purposes the argillaceous shales are entirely worthless, and the sandy shales are useful only for a top dressing,—and are not very good for that.

Slate is often quite hard to the quarryman's tools, but softens rapidly in contact with water. As a road material the fragments quickly grind to dust which has but slight binding power. Slate makes a smooth road, but one that wears very rapidly, particularly when wet. It is sometimes used as a surfacing or binding material, but is much inferior to clean sand or good stone dust.

299. Conclusion. Nearly half of the area of this country—and that part of it in which inheres perhaps nine tenths of its crop-giving value—is very illy provided with materials fitted for highway construction. For additional information concerning the road-building materials of the United States, see Preliminary Report on the Geology of the Common Roads of the United States, by Nathaniel Southgate Shaler, in U. S. Geological Survey, Fifteenth Annual Report, 1893–94, p. 255–306.

ART. 2. CONSTRUCTION.

300. The principles of construction for earth roads apply also to the construction of the subgrade for broken-stone roads (see Art. 1, Chapter III). The drainage of gravel roads by tile drains and side ditches should not be neglected (see § 98–109 and § 110–13).

301. FORMS OF CONSTRUCTION. With reference to the method of preparing the subgrade to receive the stone, there are two forms of construction—surface construction and trench construction. The surface construction consists simply in placing a layer of broken stone upon the former earth road and leaving it to be compacted by traffic. In the West many miles of road are constructed on this plan with limestone. As a rule this material readily pulverizes under the traffic, and the powder cements well; consequently the road soon binds together. Such roads are not first class but give good returns on their cost. On account of the simplicity of the construction, this form of road will not be considered further.

The trench construction consists in excavating a trench of the required width and depth, and depositing the broken stone in it.

302. With reference to the lower course of stone there are two systems of construction,—the macadam and the telford, so called after two noted English road builders (§ 274). The macadam road consists of two or more layers of crushed stone, its distinguishing characteristic being that the lower course of crushed stone is placed directly upon the earth road-bed. The telford road consists of a pavement of stone blocks set upon the road-bed covered with one or more layers of crushed stone, its distinguishing feature being the paved foundation.

303. Telford vs. Macadam Roads. Each of these systems has its earnest advocates who contend for its exclusive use.

The most important claims of the advocates of the telford construction are: (1) that the open foundation is necessary for drainage; (2) that the sub-pavement is necessary on soft or poorly drained soil to prevent the small fragments of broken stone from working down into the soil and the soil from working up into the stone; and (3) that the telford is the cheaper, since the expense of crushing is saved.

The most important claims of the advocates of the macadam system are: (1) that the drainage afforded by the telford construction is no better than that with the macadam construction; (2) that on any well drained soil there is no tendency of the stone to work down or of the soil to work up; (3) that tile drainage and macadam construction are cheaper than the telford system; and (4) that since the introduction of the machine rock-breaker, it is cheaper to crush the stone and lay the macadam foundation than to place the telford.

The view taken by different road builders in this matter is probably largely due to the necessities of the vicinity in which they have worked and to the skill with which the two systems have been applied in work which has come under their observation. The foundation which is proper in a given case is determined by the nature and condition of the soil upon which it is constructed. If the road-bed is thoroughly drained and is composed of material which will not readily soften, there will be no need of a telford foundation. If, on the other hand, the soil is retentive of moisture and can not be thoroughly drained, it may be necessary to provide a foundation which will prevent the soil from working up into

the stone and the road metal from working down into the soil. This foundation may be, according to the intensity of the difficulty to be met, a layer of sand or gravel, or a telford foundation laid directly on the soil, or a telford foundation upon a layer of sand or gravel. The choice between these two forms of construction, however, often depends upon the kind and accessibility of materials. For example, a soft laminated local stone may be used for a telford foundation, while a more expensive and harder stone is imported for the macadam top.

MacAdam insisted upon a foundation of small fragments under all circumstances, but Telford used the paved foundation only as circumstances seemed to require it. To MacAdam is due the credit of discovering the supporting power of a layer of comparatively small angular fragments of stone.

304. Forms of the Subgrade. The finished surface of the road should have sufficient crown to shed the rain water into the side ditches. There are in common use two methods of securing this crown. In one the earthen surface is made level, and the slope is given by a greater thickness of metaling at the center than at the sides; in the other, the slope or camber is given to the earth bed, and the metal has a uniform thickness. The advocates of the first system say that there is more wear at the center than at the sides, and that consequently the metaling should be thicker at the center. Those in favor of the uniform thickness say that as the pressure on the earth is practically the same at the sides as at the center, the thickness should be uniform, since the principal object of the layer of stone is to distribute the concentrated pressure of the wheel over a greater surface of the earth bed. Both forms of construction are in common use, although the preference seems to be slightly in favor of making the subgrade parallel to the finished road-surface and the stone of uniform thickness. A level subgrade is slightly cheaper to form.

Tresaguet, a Frenchman, seems to have originated in 1764 the system of making the subgrade parallel to the finished road surface. Telford finished the subgrade level, while MacAdam made it parallel to the surface of the road. Tresaguet used the form of foundation now known as telford.

Fig. 45, page 198, shows a cross section of the celebrated Shrews-

bury and Holyhead road in the west of England, built by Telford in 1815. The construction of this road, which formed a link in the direct line of communication between England and Ireland,

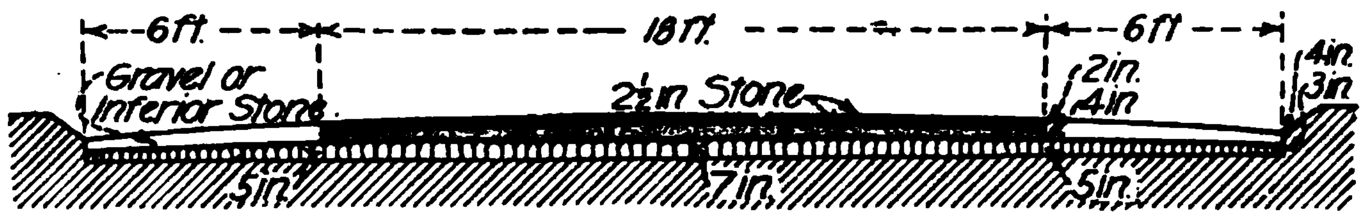


FIG. 45.—TELFORD'S SHREWSBURY AND HOLYHEAD ROAD.

was made a national undertaking, and resulted in what was at that time one of the finest pieces of road construction in the world.

The Swiss roads shown in Fig. 55 and 56, page 210, have a level subgrade.

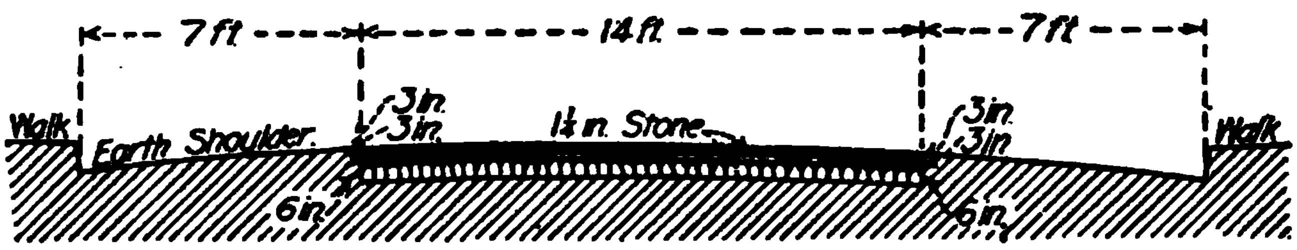


FIG. 46.—MODERN TELFORD ROAD.

Fig. 46 shows a Tresaguet or "modern telford" road as built in New Jersey. Notice that the base of the foundation is parallel to the surface of the finished road.

305. Maximum Grades. For examples of steep grades on broken-stone roads, see § 82.

306. Width. In view of the considerable cost necessarily involved in constructing a first-class broken-stone road, it is important to determine the width that should be paved. The width of way necessary for ordinary rural traffic is often over-estimated. Two wagons having a width of wheel base of 5 feet and a width of load of 9 feet can pass on a 16-foot roadway and leave 6 inches between the outer wheel and the edge of the paved way and a clearance of 1 foot between the inner edges of the loads. This extreme case will rarely occur, and hence a width of 16 feet will certainly be enough unless there is considerable rapid traffic.

The Massachusetts Highway Commission carefully measured the width of traveled way on numerous crushed-stone roads, and found that with an improved width of 15 to 24 feet,—the average being 16.1 feet,—the maximum width of traveled way averaged

14.92 feet and the width commonly traveled averaged 11.05 feet.* On this evidence the Commission concludes that "a width of 15 feet is ample except in the vicinity of the larger towns, and that 12 feet is sufficient for the lighter traveled ways, but that 10 feet is too narrow unless good gravel can be obtained for the shoulders."† The average width commonly traveled on forty-six of the 15-foot roads was 9.58 feet.

In New Jersey the width for state-aid roads is 9 to 16 feet, mostly 10 to 12 feet. The improved width of French roads varies from 16 to 22 feet (see § 89); in Austria, from 14 to 26 feet; and in Belgium there are many roads only 8½ feet wide.

307. Earth Shoulders. The preceding discussion has referred only to the width of the paved portion; but there should be an additional width of earth sufficient to keep the broken stone in place, particularly while being rolled. This strip of earth is usually called a shoulder, but sometimes and improperly a wing (see § 322). The proper width of the shoulder will depend upon the soil, the climate, and the amount of rolling it receives. Usually 2 or 3 feet is sufficient, although 5 to 7 feet is frequently provided —see Fig. 46. The Swiss road shown in Fig. 55, page 210, has a shoulder of only 18 inches. Compare Fig. 50–54, pages 209–10, and Fig. 57 and 58, page 211. An excess width of shoulder adds greatly to the cost of the road when in excavation or on embankment. The surface of the shoulder should conform to the general curve of the finished roadway. The earth shoulder serves the double purpose of holding the broken stone in place and of affording room for vehicles in passing each other. To improve the shoulders for the second purpose, they are sometimes covered with a thin coat of gravel to harden the surface. Sand shoulders are speedily hardened by the infiltration of fine stone dust and dirt washed from the surface of the road. This effect is quite noticeable with coarse sand; and is appreciable even with fine sand.

308. CROWN. The center of the road should be higher than the sides, so that the water from rains may flow rapidly into the side ditches. If originally too flat, the road is soon worn hollow, and

* Report of the Massachusetts Highway Commission for 1897, p. 31. For a summary of similar data for each township for five years, see Report for 1901, p. 47–55.

† *Ibid.*, 1900, p. 32.

the middle becomes a pool if on level ground, or a water course if on an inclination. In the former case the middle of the road is sloppy; and in the latter, the fine material washes away and leaves the larger stones bare. There has been much discussion both as to the proper amount of crown and the exact form of the transverse profile of the roadway.

309. Form of the Profile. Some claim that the upper surface should be an "arc of a circle or a flat ellipse"; and others, that it should be two inclined planes meeting at the center of the road and having their angle slightly rounded off. Both forms are in common use; the first is the more common, but apparently the latter is the better.

The following objections are urged against the curved profile: 1. The greater slope near the side causes vehicles to seek the center, and consequently the road wears unequally. 2. Owing to the excess of traffic at the center, the road soon wears hollow and holds water, which is both unsightly and a damage to the road. 3. The slope is so slight near the center that a small settlement of the subgrade causes a depression of the surface, which holds water.

The only objection to a surface composed of two planes is that the flanks wear hollow and hold water; but this objection has less force than any of the three against the curved profile.

310. *Curved Profile.* Although the curved profile is usually referred to as being "an arc of a circle or a flat ellipse," it is usually laid out as the arc of a parabola. However, the difference of curvature is not material.

To lay out the parabolic arc proceed as follows: In Fig. 47, AC is the crown, i. e., the difference in height between the side and the center. AB represents a horizontal line through the crown. In street pavements A is usually the top of the curb. The curved

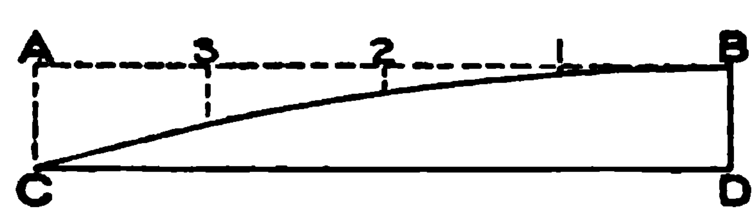


FIG. 47.—CURVED PROFILE.

line BC represents the surface of the finished road. To find the distance from AB down to the line BC, divide the half width of roadway, AB, into any number of equal parts, say, n, and desig-

nate the distance from the point 1 on AB vertically down to BC by x; then by the principles of the parabola, $x = \frac{AC}{n}$, and the distance from point 2 down to the road surface is $2^2 x$ or $4x$, and the distance from 3 is $3^2 x$ or $9x$. In practice a string with knots in it to represent the points of division of AB is stretched from the top of the curbs or from stakes driven at the edge of the broken stone, and then the ordinates computed as above are measured with a pocket rule.

311. There are a number of arbitrary rules for securing a curved profile, of which the following is one of the most elaborate, the most scientific, and the most easily remembered: "Divide the roadway into three equal parts, and starting from the center give a fall of 0.03 ft. per foot for the first part, 0.04 ft. for the second section, and 0.05 ft. for the last section. If the roadway is extremely wide, divide the half roadway into four parts, and give a fall of 0.02, 0.03, 0.04, and 0.05 ft. per foot to the respective sections. If the roadway is very narrow, divide the half roadway into two parts, and give falls of 0.04 and 0.05 ft. per foot to the two sections respectively."

This rule gives more slope at the center and less at the sides than the parabolic section, and for roadways of medium width, it gives an average transverse slope of half an inch to the foot or 1 in 24. This rule was used on the road shown in Fig. 50, page 209.

312. *Two-plane Profile.* When the surface consists of two planes meeting at the center, the profile is very easily constructed or tested. In Fig. 48, AC represents the crown or difference between the side and the center, CB is the finished surface, and AB is a horizontal line. Divide the half width AB into n equal parts,

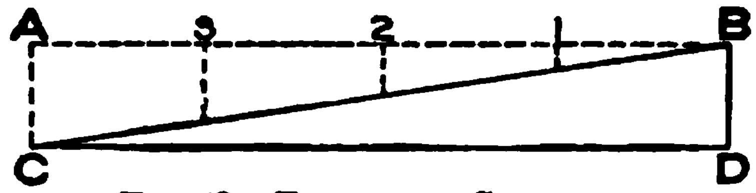


FIG. 48.—TWO-PLANE SURFACE.

and then the ordinate from point 1 down is $\frac{AC}{n}$, and that from 2 is $2\frac{AC}{n}$, and that from 3 is $3\frac{AC}{n}$, etc.

Regularity and evenness of crown is more important than the mathematical form of the cross section. A slight depression becomes very conspicuous when filled with water; and besides the water standing upon the surface softens it and tends to increase the depression. With a little care in filling the low places developed during the rolling, it is possible to build a broken-stone road with an almost mathematically exact crown.

313. Amount of Crown. The proper amount of crown depends chiefly upon the method of making repairs. If new material is added only, say, each second or third time the surface is smoothed up, then the crown should be greater to compensate for future wear; but if new material is added practically continuously, the crown may be considerably smaller. The rate of transverse slope should be smaller on wide than on narrow streets, to prevent the water from unduly washing the surface near the sides. There should be more crown on steep grades than on flat ones, to throw the water quickly to the side ditch and to prevent it from flowing down the grade on the surface of the road and washing out the binder.

Sometimes wide boulevards, with curved profile and maintained by continuous repairs, have a crown of one sixtieth of the width, or a rise of 0.4 inch per foot from side to center, or an average slope of 1 in 30. The French roads, which have a curved profile and are maintained by the system of continuous repairs, have a crown of one fiftieth of their width, or a rise from side to center of 0.5 inch per foot or a slope of 1 in 25. Many of the better cared for streets and park drives have a crown of one fortieth, or a rise from side to center of 0.6 inch per foot or an average slope of 1 in 20. On the state-aid roads in Massachusetts (narrow roads and continuous repairs), the surface consists of two planes meeting in the center, the transverse slope being ¾ inch to a foot or 1 in 16. Broken-stone roads made of soft stone and maintained by periodic repairs frequently have an original crown of one twelfth—an average slope of 1 inch to 1 foot or 1 in 12.

In Providence, R. I., the following relation between the grade and the crown has been established:

LONGITUDINAL SLOPE.	TRANSVERSE SLOPE.
½ to 4 per cent	1 in 25
4 to 6 " "	1 in 20
6 to 9 " "	1 in 12½

314. With a broken-stone road, the method of making repairs has more weight in determining the amount of the crown than in the case of either an earth road or a gravel road. The earth road is easily and cheaply maintained by what may be called the system of continuous repairs with the scraping grader, which restores or rather maintains the crown. With a gravel road, when it is necessary to restore the crown by adding more gravel, it is usually sufficient to put on only a thin layer and wait a comparatively short time for traffic to consolidate it. With a broken-stone road, if the crown or rather the surface is to be perpetually maintained, it is necessary to keep a man upon a short stretch of the road practically all of the time, adding thin patches of stone in first one place and then another, a method so expensive that it is practiced in this country only on park drives, boulevards, etc.; and if the crown is to be restored periodically, it is necessary to add a considerable layer of stone and consolidate it by long continued and expensive rolling and sprinkling, and on account of the expense of this operation and the obstruction to traffic it is customary to lay such a thickness of stone and to give the surface such a crown as not soon to require a repetition of the process. Therefore it happens that broken-stone roads are often built with a crown nearly, if not quite, equal to that of good earth roads, and with more perhaps than is given to good gravel roads.

315. There is a slight advantage of a very high crown for a broken-stone road, particularly for one that is not frequently cleaned. If the crown is great, the rains will the better wash the surface clean. Dirt upon the surface is not only unsightly, but is also detrimental since it holds the water and softens the surface. Of course the material washed by rains into the gutter must eventually be removed; but this can be removed more cheaply from the gutter with a scraping grader at comparatively long intervals, than from the surface with brooms or scrapers at short intervals. The practice of making a high crown is somewhat com-

mon in villages using soft road metal and having earth gutters and only surface drainage.

This advantage of a high crown is less for a country road than for a village street, since the wind usually gets a better sweep at the former than at the latter.

316. Road Level. The transverse curvature of the surface of the road may be tested by the use of the instrument shown in Fig. 49. It consists of a straight edge, *E F*, about 8 feet 6 inches long made of a 1-inch by 6-inch pine plank, surmounted by a frame which serves as a handle and to support the plumb-line.

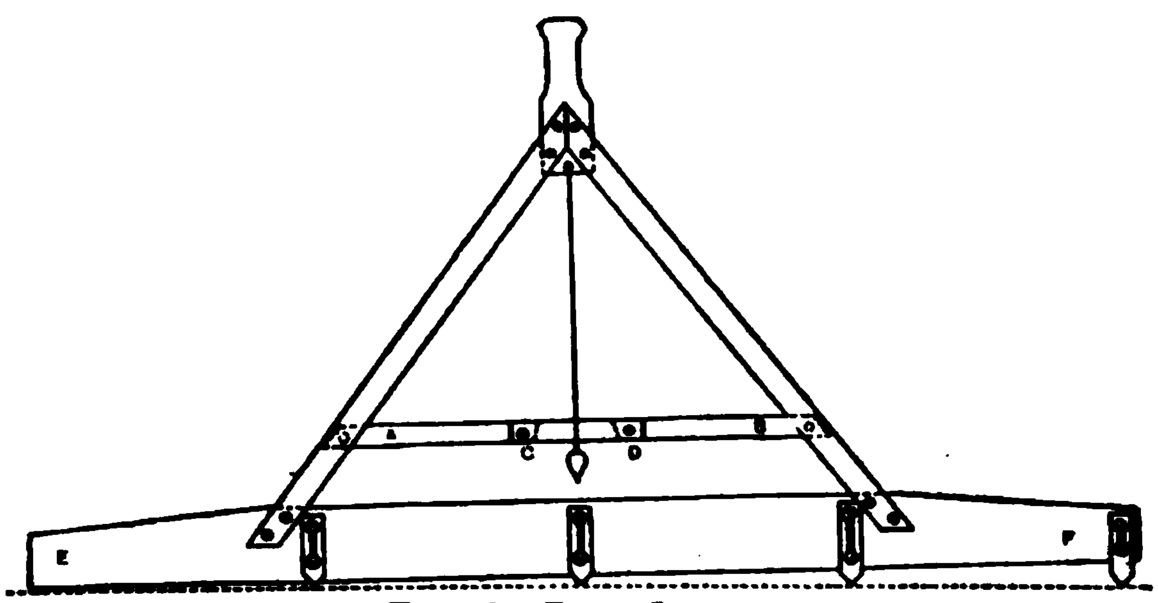


FIG. 49.—ROAD LEVEL.

The general construction is sufficiently shown in Fig. 49. The plumb-bob can be bought at any hardware store for a few cents. On the front side of the piece *A B*, is screwed a piece *C D*, the middle half of the back of which is cut out just enough to leave room for the plumb-line to swing.

To adjust the instrument proceed as follows: Drive two nails 8 feet 4 inches apart into the floor with their heads at approximately the same level. Set the straight edge *E F* upon the nails, and make a temporary mark on the upper edge of *A B* or *C D* to indicate the position of the plumb-line; then reverse the straight edge end for end, and again mark the position of the plumb-line. Make a permanent mark square across the top of both *A B* and *C D* midway between the two temporary marks, and drive down the higher nail until the plumb-line hangs opposite this mark; then the lower edge of *E F* is exactly level.

To fit the above instrument for use in testing the crown of a road, it is necessary either (1) to fasten upon the piece *E F* a board

whose lower edge is cut to the proper curve, or (2) to attach strips the ends of which indicate points on the curved profile. If the first method is employed, the curvature of the lower edge of the template may be determined by the method of § 310; and if the second method is preferred, the amount that the several strips should project beyond the edge of *E F* may be computed by the method of § 310. If the strips are used, it is most convenient to slot them and attach them with round-headed wood screws, so that the strips may be more accurately adjusted to position.

The instrument is of use to an inexperienced person in inspecting the curvature of the crown of a broken-stone road.

317. The above instrument may easily be modified so as to be of service in inspecting the longitudinal slope of the side ditches, for which purpose neither the strips projecting below the straight edge nor the template are required. Without these, the instrument is simply a level, and it only remains to graduate it. This may be done as follows: Proceeding as in the second paragraph of § 316, drive two nails into the floor until they are exactly at the same level; and then adjacent to one of these nails, drive another until its head is exactly 1 inch above the adjoining one. Set the straight edge *E F* upon this and the opposite nail, and mark the position of the plumb-line. The lower edge of *E F* is now on a grade of 1 inch in 8 feet 4 inches, or 1 inch in 100 inches, or 1 foot in 100 feet. By obvious modifications of the above process, the upper face of either the piece *A B* or *C D* can be graduated to correspond to any grade.

In this form, the instrument is of material help in determining whether the bottom of a ditch has a uniform grade. The instrument is not capable of mathematical precision, and hence should not be employed to run long lines of levels when accuracy is required; but it is valuable in checking the grade between points determined by an engineer's leveling instrument. To obtain the highest accuracy, the plumb-line should be fine and smooth.

318. THICKNESS. The object of placing a layer of broken stone upon the trackway is to secure (1) a smooth hard surface, (2) a water-tight roof, and (3) a more or less rigid stratum which will distribute the concentrated pressure of the wheel over an area of the subgrade so great that the soil can support the load without

indentation. The smooth surface and the tight roof depend upon the quantity and quality of the binding material (§ 345–49); and the rigidity of the layer depends somewhat upon the binder, but chiefly upon the thickness of the stratum. The supporting power of the subgrade depends upon the nature of the soil and particularly upon the drainage. Therefore the minimum thickness of broken stone depends upon the nature of the soil, the drainage, the traffic, and the binding material; and the initial thickness depends upon the amount of wear permitted before new material is added. If repairs are continuous, the initial thickness may be the minimum; but if repairs are made periodically, the initial thickness must be equal to the minimum thickness plus the amount allowed for wear. After a road has been worn down 3 inches, it is usually so uneven as to require re-surfacing; and therefore it is uneconomical if the road in this stage is much or any thicker than the minimum required to prevent its breaking through.

There has been much discussion and there is a great difference of opinion as to the proper depth of a broken-stone road. The depth considered necessary by the most extreme advocates of thick roads has decreased with the introduction of more improved methods of construction—particularly the use of binder and a steam roller,—and as the advantage of thorough under-drainage has been better appreciated. Early in the century a depth of 18 to 24 inches was frequently considered necessary for heavy traffic, but later it was reduced to 12 or 15 inches, while now 6 inches, or less, is usually considered sufficient.

319. The concentrated load of a wheel is transmitted through the broken stone to the earth in lines diverging downward, and the wheel may be assumed as resting upon the apex of a cone whose base is upon the earth subgrade. The sides of this cone probably make an angle of about 30° with the vertical.* It is not wise to attempt to find a mathematical relation between the load on the wheel and the resulting pressure on the earth, since neither the angle of the cone nor the distribution of the pressure on the base of the cone are known. It is reasonably certain, however, that

* For information of a little interest in this connection, see §19 of Materials of Construction by Prof. J. B. Johnson. New York, 1897.

the supporting power of a crushed-stone road varies as the square of the depth. This is an important relation to bear in mind when a road is to be strengthened.

The Massachusetts Highway Commission assumes* the pressure to be uniformly distributed over an area equal to the square of twice the thickness of the layer of crushed stone, which is equivalent to assuming that the sides of the cone make an angle of 48½ degrees with the vertical and that the pressure is uniformly distributed over the base. According to this theory, if t = the thickness of the stone in inches, w = the maximum weight in pounds per wheel, and p = the supporting power of the soil in pounds per square inch, then

$$t = \sqrt{\frac{w}{4p}}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (1)$$

The Commission has applied this formula to roads already constructed to determine the safe bearing power of the soil, and concludes that non-porous soils, drained of ground water, at their worst will support a load of 4 pounds per square inch, and that sand and gravel will safely support 20 pounds per square inch.†

Although the method of arriving at equation (1) is not correct, the manner of deducing the supporting power of the soil in a measure offsets the error, and consequently the formula may be used with some confidence.

320. In Massachusetts the thickness for state-aid roads varies from 4 to 16 inches, the standard for crushed stone with macadam foundation on well drained sand or gravel being 6 inches, "which appears to be ample for the heaviest traffic."‡

In New Jersey, on state-aid roads, the depth of stone with macadam foundation varies from 4 to 12 inches, but is generally 6 inches; and the telford roads are from 8 to 12 inches thick, usually 8 inches. Most of the roads have a macadam foundation, the telford being used as a rule only where field stones suitable for a telford foundation are found alongside of the road.

* Annual Report for 1901, p. 15.

† Massachusetts Highway Commission, Report for 1901, p. 15.

‡ *Ibid.*, 1900, p. 32.

321. The experience at Bridgeport, Conn., is frequently cited to prove that a comparatively thin road is sufficient. Something like 60 miles of 4-inch macadam roads built in that place gave excellent service even under a heavy traffic. The conditions were very favorable for a thin road: (1) the soil was sand or sandy loam, and had fairly good natural drainage; (2) the subgrade was thoroughly rolled with a 15-ton roller; (3) the broken stone was trap, which is hard and durable; (4) the binder was hard and durable, being either stone dust or siliceous sand, and was free from clay or loam; (5) the binder was worked in until the voids in the crushed trap were practically filled, the effect of frost being thus reduced to a minimum and the soil being prevented from working up from below; (6) the stone was thoroughly consolidated with a steam roller of adequate weight; and (7) the roads were maintained by the system of continuous repairs.

The experience at Bridgeport has been repeated at several other places; but such experiences should be regarded as the exception, rather than the rule, since 4-inch roads are adequate only under favorable natural conditions and with the most painstaking construction and careful maintenance. The fact that a very thin road can carry the traffic does not prove that such a road is the most economical, for the increased cost of maintenance may more than counter-balance the decreased cost of construction. The engineer should always attempt to construct economically and adapt his construction to fit the natural conditions.

In many cases the problem is whether to construct a thick road on the undrained soil or to secure thorough underdrainage and build a thin road. The latter is usually better and cheaper.

322. Wings. In the preceding discussion of the thickness of the road metal it has been assumed that the depth was practically uniform; but some engineers, in recognition of the fact that there is less travel nearer the sides than at the center, make the thickness of a strip on each side considerably less than that at the center. The thin strips on the sides are called wings. Fig. 50, page 209, a portion of the Swedesboro road in Gloucester County, New Jersey, shows a cross section of this form. This construction is somewhat common in New Jersey, both with telford and macadam foundations, and has been adopted by the U. S. A. engineers for

macadam roads in Porto Rico.* The wings are usually 2 or 2½ feet wide. A road with wings is simply a compromise between a narrow thick road and a wide thin one.

FIG. 50.—TELFORD ROAD WITH MACADAM WINGS.

323. EXAMPLES OF CROSS SECTIONS. Fig. 45, page 198, shows a cross section of a telford road built under Telford's direction in 1815. Fig. 46, page 198, shows a New Jersey telford road. Fig. 50 shows a telford road with macadam wings. Fig. 51 shows the

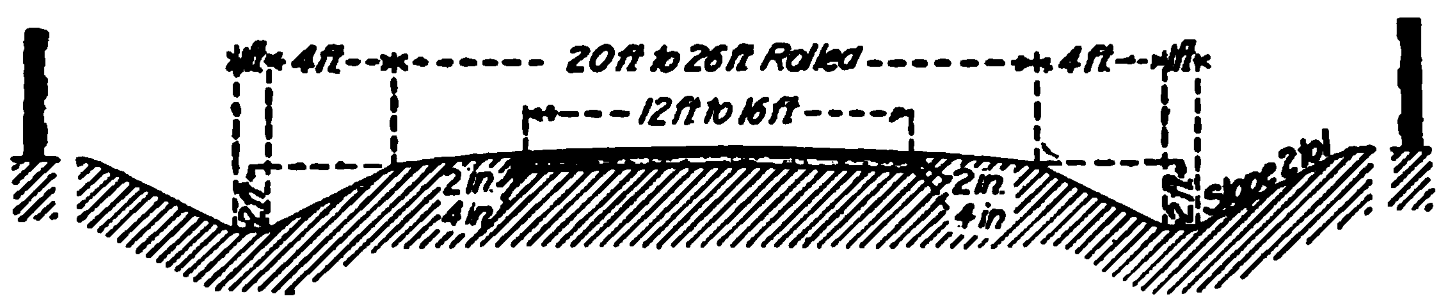


FIG. 51.—STANDARD SECTION FOR NEW YORK STATE-AID ROADS.

standard cross section for state-aid roads in the state of New York.† Fig. 52 is a section of a road in Flushing, Long Island,

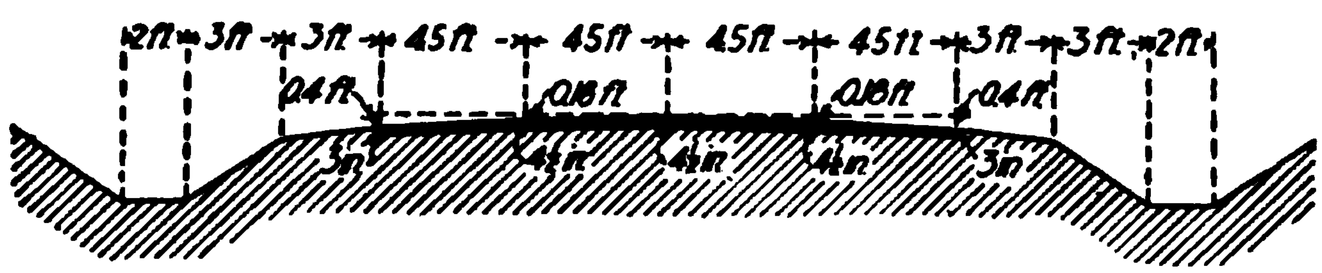


FIG. 52.—GENERAL SECTION OF FLUSHING AND JAMAICA ROAD.

near New York City. This road is crowned according to the rule stated in § 311. Fig. 53 and 54, page 210, are the standard cross section in excavation and on embankment, respectively, for state-aid roads in Massachusetts.‡ "These are the sections generally employed, but may be modified to suit the conditions; for example, the thickness of the crushed stone may be made either less or more than shown, if the local conditions justify;

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* *Engineering News*, Vol. 45, p. 202.

† Report of the State Engineer and Surveyor, 1899, p. 321; or Bulletin No. 1, April 1899, p. 9.

‡ From official drawings, by courtesy of Austin B. Fletcher, Secretary of the Massachusetts Highway Commission.

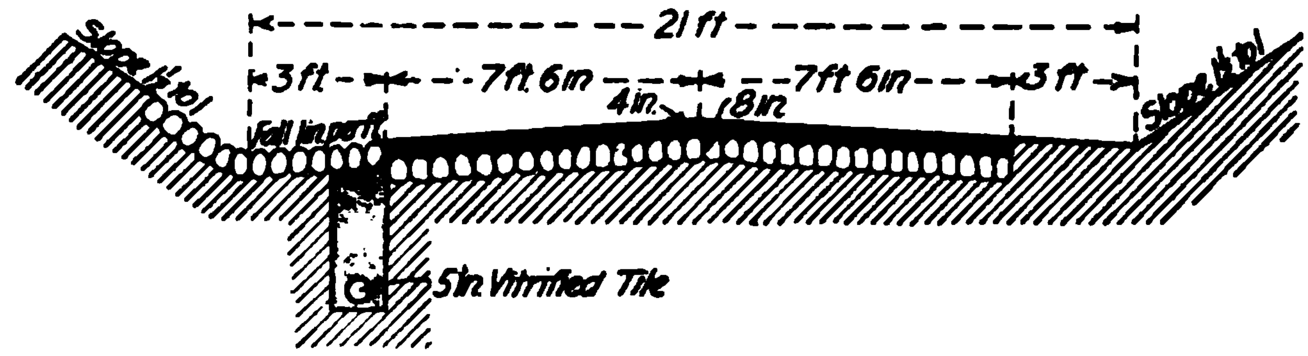

FIG. 53.—STANDARD SECTION IN EXCAVATION FOR MASSACHUSETTS STATE-AID ROADS.

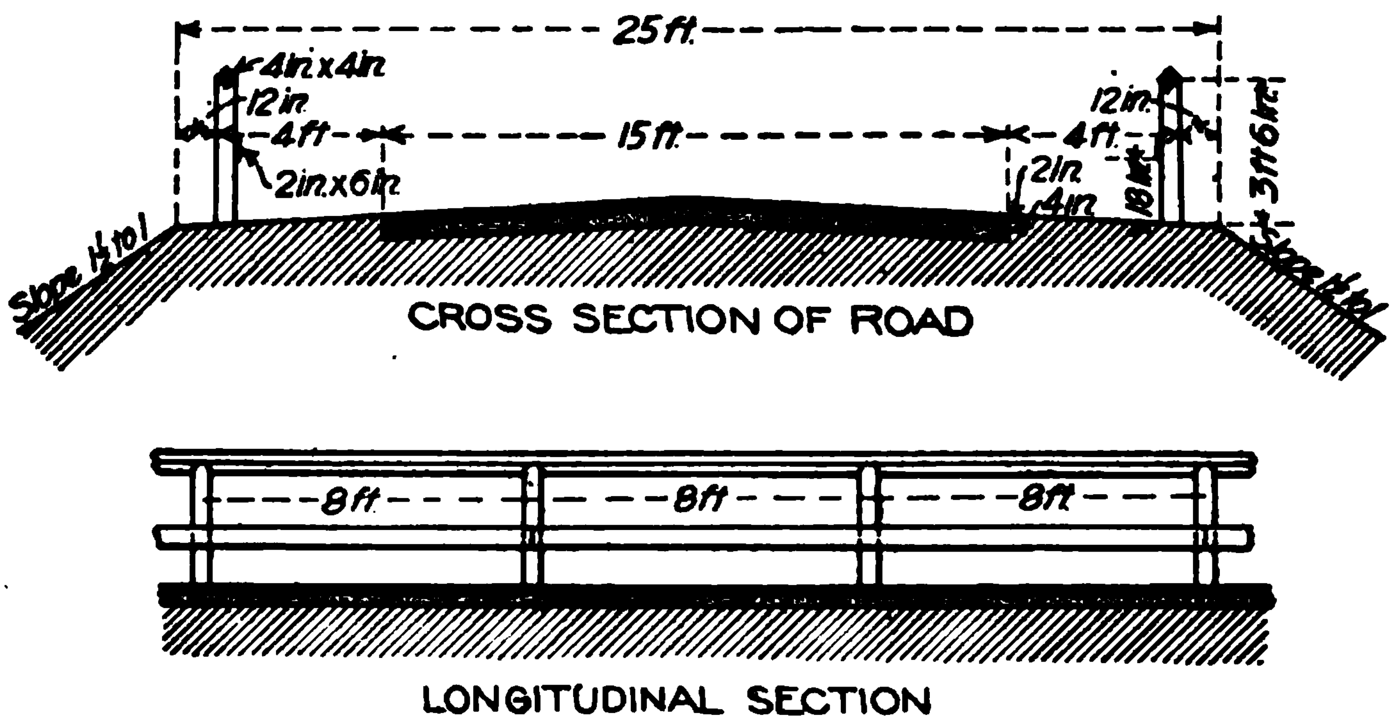

FIG. 54.—STANDARD SECTION ON EMBANKMENT FOR MASSACHUSETTS STATE-AID ROADS.

and where very heavy soil is encountered, 2 inches of gravel are put under the telford."

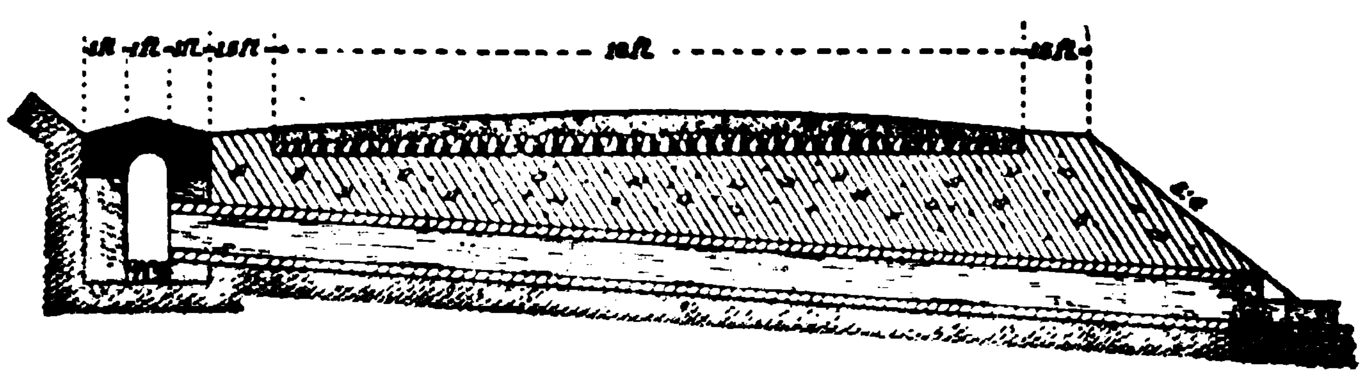

FIG. 55.—CLASS-II ROAD, CANTON OF BERN, SWITZERLAND.

Fig. 55 and 56 show sections of two Swiss roads.*

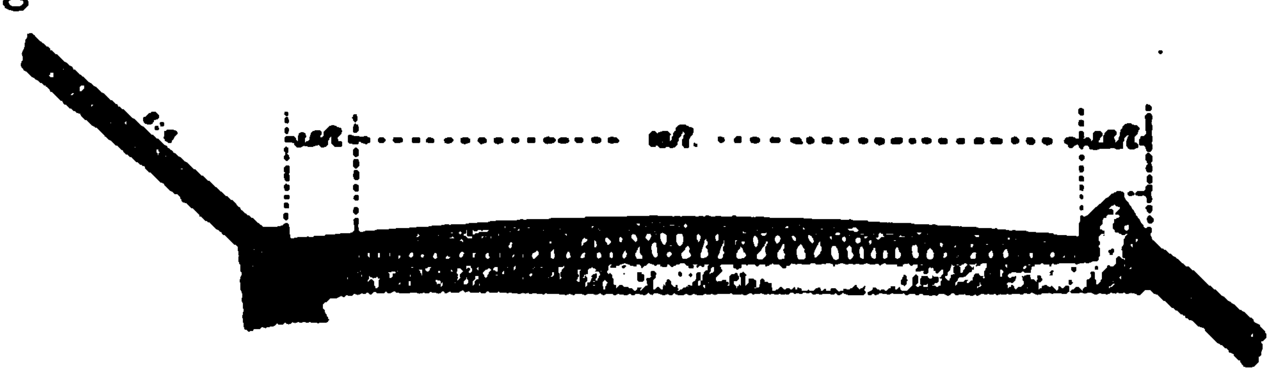

FIG. 56.—CLASS-III ROAD, CANTON OF BERN, SWITZERLAND.

* Special Consular Reports on Streets and Highways in Foreign Countries, Department of State, U. S. A., 1897, p. 238.

Fig. 57 shows a typical road in the Department of Bas-Rhin, France.* The broken stone is 6 inches deep, 19 feet 8 inches wide, and has a crown of one fiftieth.

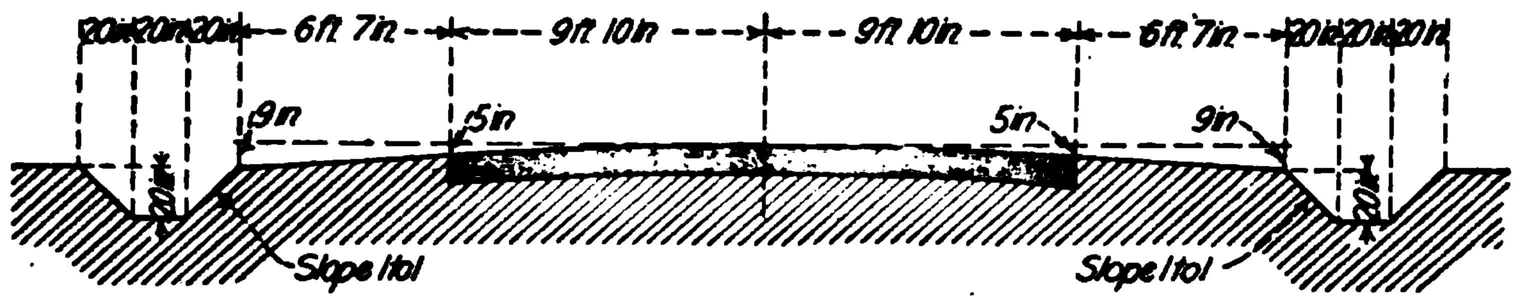

FIG. 57.—TYPICAL ROAD IN DEPARTMENT OF BAS-RHIN, FRANCE.

Fig. 58 is a typical French road in the Department of Seine-et-Oise.* The crown of the roadway is one fortieth, and the transverse slope of the sidewalks is 1 in 20.

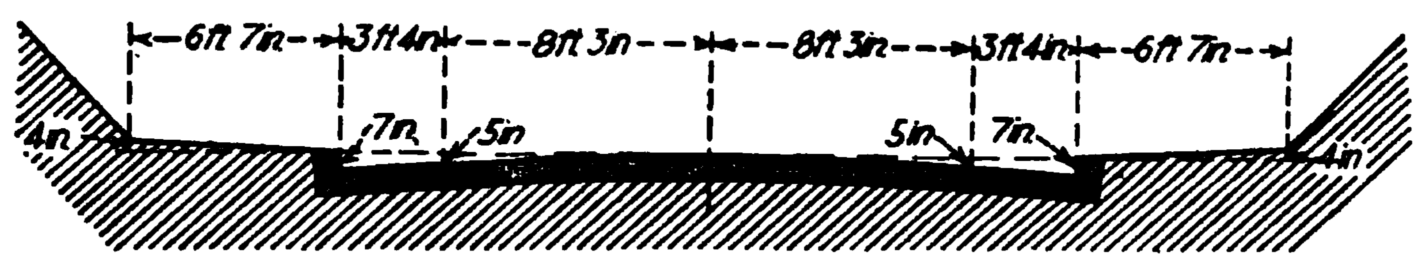

FIG. 58.—TYPICAL ROAD IN DEPARTMENT OF SEINE-ET OISE, FRANCE.

324. PERMISSIBLE GRADES. For a general discussion of the subject of maximum and minimum grades, see § 76–86; and for examples of maximum grades for broken-stone roads, see § 82–85.

325. PREPARING THE SUBGRADE. The broken stone is designed to take the wear of hoofs and wheels, but the earth foundation must support the load, and therefore any road which is constructed without giving due attention to the earth road-bed is wrong from the start, and will never be a good road until the defect is remedied.

For instructions concerning the construction of embankments and excavations, see § 119–22. In building an embankment upon which broken stone is to be laid, every reasonable care should be taken to prevent uneven settlement. It is sometimes advisable to delay the laying of macadam for at least a year in order to give the embankment time to settle, for it is impossible to construct an embankment of earth more than a few feet in height without having subsequent settlement. If this settling took place evenly all along the embankment, no particular harm would be done to the

* Rockwell's Roads and Pavements in France, p. 52—from Monsieur A. Debauve, Ingénieur en chef des Ponts et Chaussées.

macadam laid upon it; but owing to the difference in the soils composing embankments, and also in the way the earth is dumped, there is always a tendency for some parts to settle more than others.

Sometimes the road surface is placed so low that it forms a gutter to drain the adjacent fields, which of course is very objectionable. Occasionally the earth from the side ditches and from the trench in which the stone is placed, is deposited at the side of the right-of-way instead of being used to raise the road surface. In this connection, see § 126.

326. After the subgrade has been brought to the proper form (§ 305), it should be rolled thoroughly—both to consolidate it and to discover soft spots. For a discussion of road rollers, see § 336–40.

In rolling, quicksand spots are sometimes discovered, in which case the troublesome material should be excavated and suitable material be substituted. If the road-bed be of sand or of material of such a nature as to push along in a wave in front of the roller, a thin layer of broken stone or gravel strewn over the surface will enable the roller to consolidate the road-bed. If the surface is clay that sticks to the roller, sprinkle a thin layer of sand or cinders over the surface.

327. SETTING THE TELFORD. The distinguishing feature of a telford road is its paved foundation. After the road-bed has been brought to the proper form and been rolled, rough stones are set upon the surface to form a pavement 5 to 8 inches thick, the thickness depending upon that to be given to the finished road (§ 318), the general practice being to make the paved foundation about two thirds of the total thickness of the road. The practice of Telford was to grade the road-bed flat, and then construct his pavement deeper in the middle than at the sides, using for a roadway 16 feet wide, stones about 8 inches deep at the middle and 5 inches at the sides. This practice is still followed by some engineers, but it is now more common and usually considered preferable to make the surface of the road-bed parallel to the finished surface and the pavement of uniform thickness. Fig. 45, page 198, shows a telford road with a level subgrade; and Fig. 46, page 198, a telford road with the subgrade parallel to the finished surface.

The size of the stones for the telford pavement is of no great

importance, at least there is a great difference in the practice of the best road builders. The width of these stones varies from 3 to 10 inches, 3 to 6 being most common; and the length varies from 6 to 20 inches, 8 to 12 being most common. It is desirable to have the width on any particular job somewhat nearly uniform, and the stones in any course should be still more nearly equal. The stones are set upon their widest edge with their greatest length across the road, the joints being broken as much as possible. Each stone should stand independently of its neighbor, i. e., one stone should not lean against another. The irregularities of the upper surface are then broken off with a hammer, and the interstices between the stones are filled with spalls lightly driven into place with a hammer or a crow-bar. This knocking off of the projecting points and the driving of spalls into the interstices should not be done so near the face of the pavement as to dislocate the stones last set. It is frequently specified that no wedging shall be done within 10 or 15 feet of the front edge of the pavement. After the projecting points have been knocked off and the interstices have been filled with stone chips or ordinary crushed stone, the pavement is usually rolled. It is usually specified that the roller shall not go nearer to the front of the pavement than 25 to 30 feet.

The cardinal requisite of a telford foundation is the interlocking of the stone closely and compactly together by barring, wedging, and rolling until the entire structure is brought in action to resist disturbance as a single mass.

328. CRUSHING THE STONE. The introduction of a machine for breaking the material greatly cheapened the cost of broken-stone roads. The rock crusher was introduced into America in 1860, before which time the stone was broken by hand with hammers on the side of the road. Coincident with the introduction of power for breaking the stone, came the revolving screen which permitted the fragments to be assorted as to size—an important feature, as we shall soon see.

Formerly there was much discussion as to the relative merits of hand- and machine-broken stone; but the difference in value is so slight and the difference in cost, particularly in this country, is so great that the question has been answered practically in favor of the machine-broken stone.

329. Forms of Crushers. There are two types of crushers now in common use. The older one, often called the Blake after the original inventor, consists of a strong iron frame, near one end of which is a movable jaw. By means of a toggle-joint and an eccentric, this jaw is moved backward and forward a slight distance. As the jaw recedes the opening increases and the stone descends; as the jaw again approaches the frame, the stone is crushed. The maximum size of the product is determined by the distance the jaw plates are from each other at their lower edge. This machine is also frequently called the oscillating breaker. Fig. 59 shows

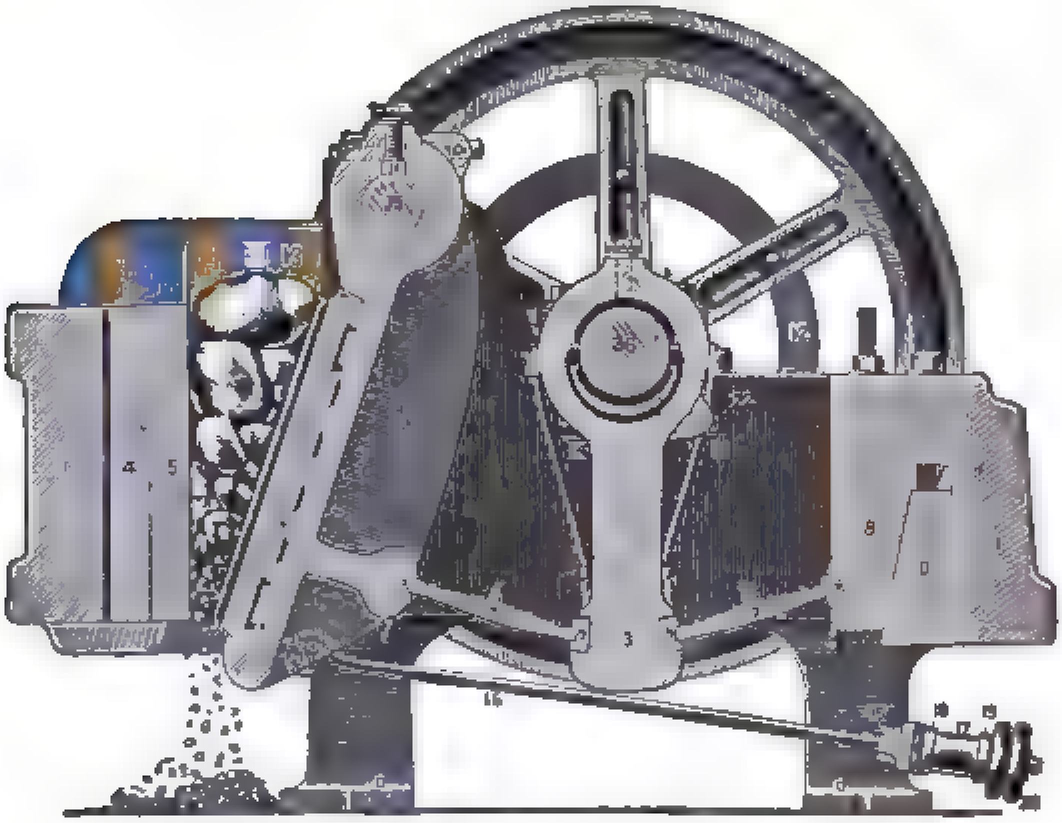

FIG. 59.—OSCILLATORY STONE CRUSHER.

one form of this type. The size of the product is regulated by raising or lowering the wedge 10, Fig. 59, or by inserting a different pair of toggles,—7, Fig. 59.

The second form of crusher, called the Gates after the original inventor, consists of a solid conical iron shaft which is supported within a heavy iron mass shaped somewhat like an inverted bell. By means of an eccentric shaft a rocking and rotary motion is given to the shaft, so that each point of its surface is successively brought near to and removed from the surface of the bell, which causes the stone to be successively crushed as it descends. Fig. 60

shows one form of this type of crusher. An adjustment permits a variation in the size of the product. This form is often called the rotary breaker.

The rotary crusher has one advantage over the oscillatory form. The latter breaks the stone and then draws back, the stone dropping down ready to receive the thrust of the jaw when it is next pushed forward; and thus time is lost while the jaw is reced-

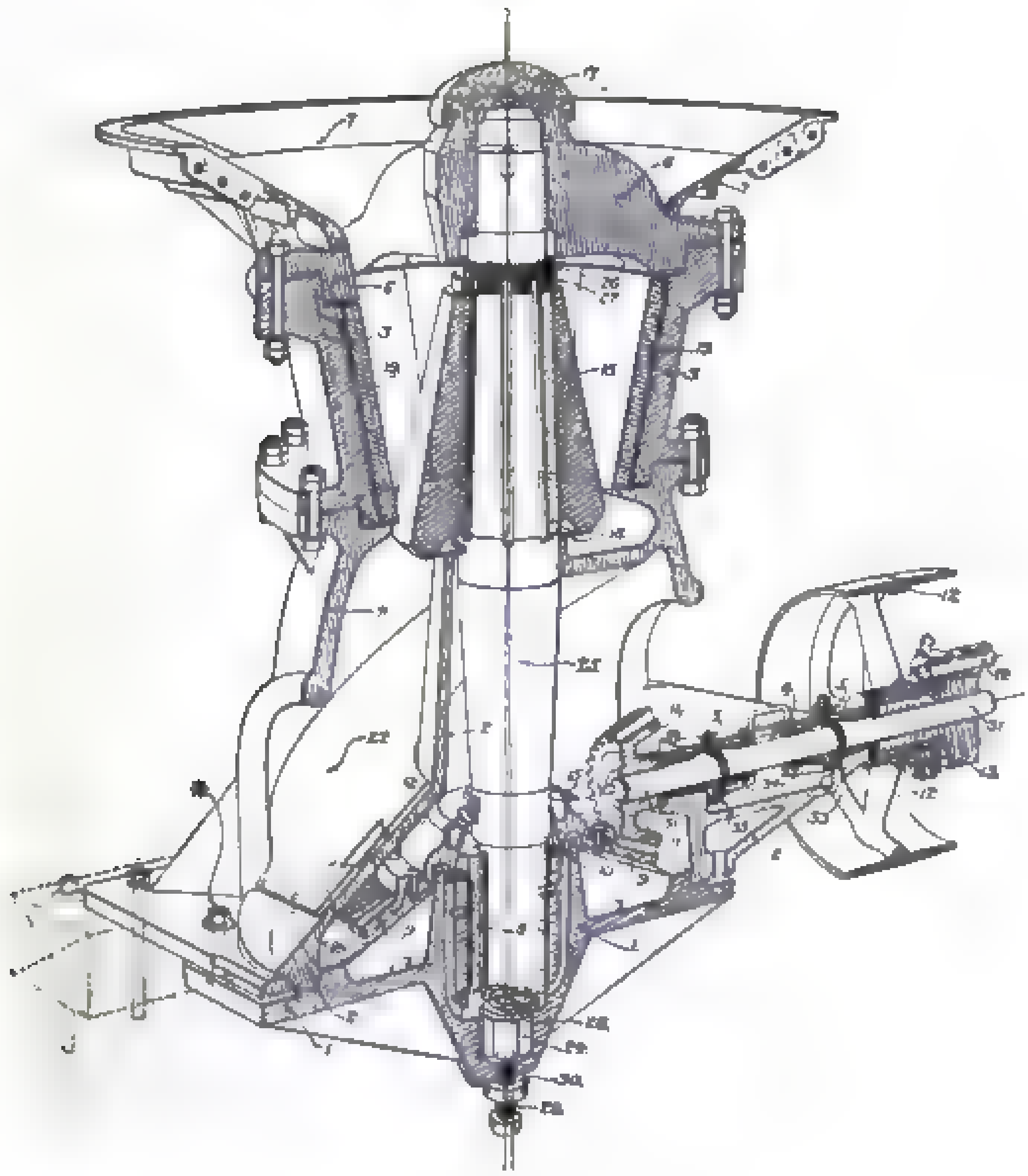

FIG. 60.—GYRATORY-ROCK CRUSHER.

ing, and more power is required to start without momentum against the stone. With the rotary crusher no time is lost in gathering for a new stroke, and the power is uniform and continuous.

Both machines are driven by steam or occasionally by horse-power. Both are made in a great variety of sizes, capable of crushing from 10 to 200 tons per day. There are many conflicting

claims as to the relative merits of the two types, but both are very excellent machines. In determining the relative economic efficiency, it is necessary to consider the output, the power required, the cost of repairs, the expense of moving the machine from point to point, the amount of sledging required, etc.

330. Arrangement of Plant. More important than the economical working of the machine, is the general arrangement of the entire plant for handling and crushing the stone. The plant should be arranged, if at all possible, so that the stone may be delivered from the quarry or from the field on a level with the mouth of the crusher, and thus save lifting the entire product by hand in throwing it into the machine. The crushed stone should be elevated to bins or pockets, one for each size, so arranged as to discharge directly into the wagons or carts that haul it to the road—see Fig. 61. The bins should have a considerable capacity, so as to prevent

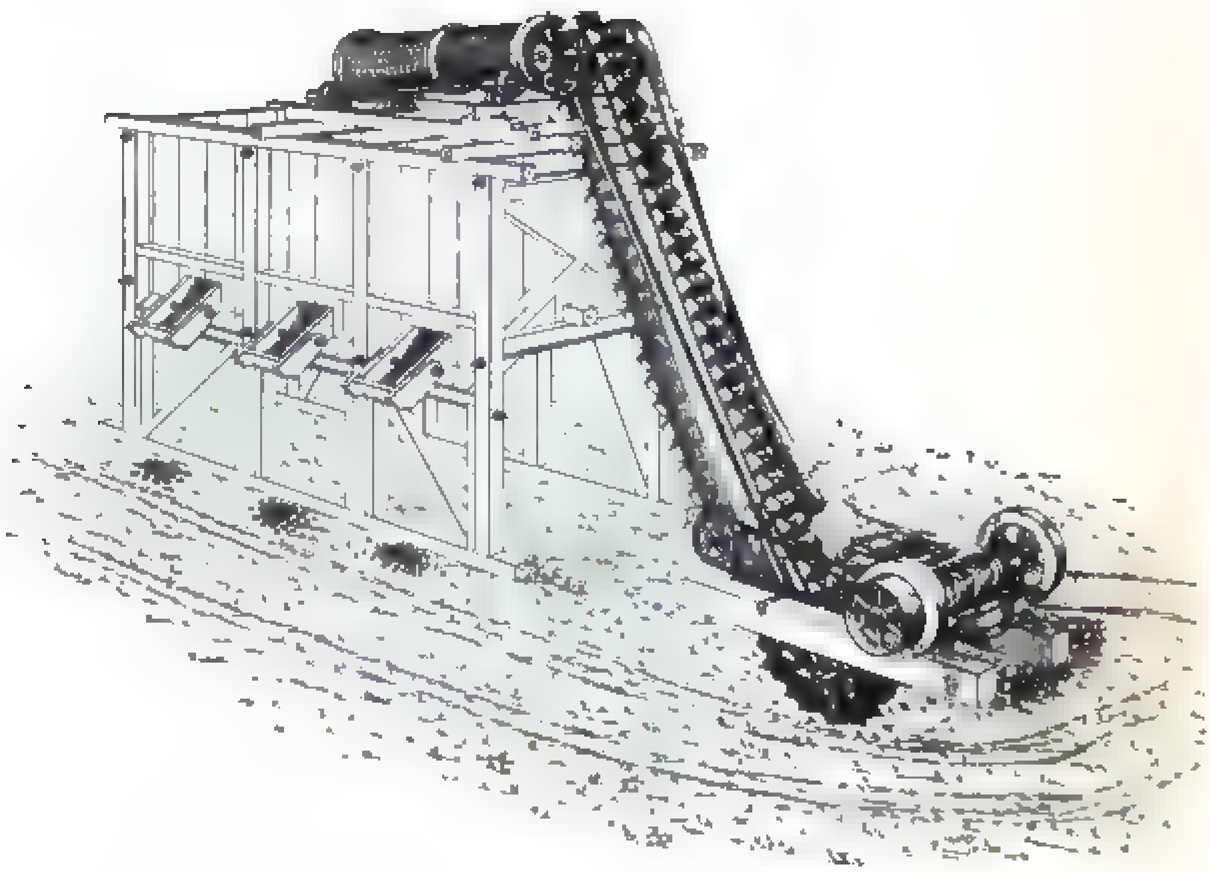

FIG. 61.—ARRANGEMENT OF STONE-CRUSHING PLANT.

stoppage of the machine if the roads are too bad to haul or if for any other reason the removal of the crushed stone is delayed. There should be ample room about the plant to prevent the interference of the teams in going and coming. To secure all of these conditions

requires a careful study of the problem, and a proper adjustment of them is a matter greatly affecting the cost of the product. In permanent plants these conditions are very carefully attended to; but in temporary outfits it is not always possible to secure an ideal adjustment. In many cases the arrangement could be greatly improved at comparatively little expense.

A well arranged stone-crushing plant costs from $1,500 to $2,500, the cost of an average plant being divided about as follows: a 9″ × 15″ crusher, $700; a rotary screen and elevator, $300; engine and boiler, $600; portable bins, $300; miscellaneous fittings, $100; total $2,000. For data on the cost of crushing stone, see § 353.

331. SIZES OF STONE. The size of stone used for road metal depends upon the hardness and toughness of the stone and upon the weight of the traffic. The harder and tougher the material, the smaller it may be broken without danger of its crushing or shattering under the load of wheels and the impact of hoofs; and the harder and tougher a stone, the smaller it must be broken in order that it may compact well in the road. The stones in the top course should be larger for heavy traffic than for light traffic, to prevent their being ground to powder. Larger stones can be used in the bottom layers of a road than at the top.

One of MacAdam's rules was to exclude any fragment weighing more than 6 ounces. Telford's limit was 8 ounces. A 1½-inch cube of compact limestone weighs about 6 ounces. Another of MacAdam's rules was to exclude any stone that could not readily be put into a man's mouth. These rules are frequently quoted, even now, although improvements in road machinery have made them inappropriate with present methods. When these rules were established, the road was not rolled but was compacted by traffic; and as the stone was broken by hand little or no fine material was produced, and hence the road was bound chiefly by manure and dirt brought on by the traffic. Rolling and the use of stone dust for a binder make a material difference in the sizes of the stone permissible.

The bottom course of a macadam road built of soft stones is often composed of fragments 3 to 4 inches in greatest dimensions; but if it is built of hard tough stone, the sizes are 2 to 2½ inches. The size of rock in the lower courses is not so important as that for

the surface course (see § 332). The top course of hard tough stones is usually 1 to 2 inches for heavy traffic, and ½ to 1 inch for light traffic. It is often claimed that a smooth road can not be built with stones 2 inches in diameter; but with sufficient rolling and a good binding material, a comparatively smooth road may be secured with such stones, and the road will last much longer than one built of finer material.

The custom is to lay the stone in courses of substantially one size, although some road builders prefer to have the sizes mixed when thrown into the road. The only advantage of the latter practice is that with a skilful proportioning of the sizes less rolling is required; but it is objectionable owing to the difficulty of getting the several sizes properly proportioned and keeping them thoroughly mixed. There is generally too much fine material in the mixed sizes, which makes the road wear rapidly and unevenly.

Connected with the crusher and run with the same power is generally a rotary screen having meshes of three sizes—usually about ½, 1½, and 2½ inches. Fig. 61, page 216, shows a common arrangement of crusher, elevator, screen, and bins.

332. For economic reasons the size of stone in the several courses and their thickness should be adjusted so as to use, if possible, all of the output of the crusher. The output of the various sizes varies considerably with the character of the stone. With a hard stone, half or more of the product of the crusher will not pass through the ½-inch screen; while with field stones one half may pass through such a screen. The last gives more "fines" or "screenings" than can be used profitably during construction, but the surplus is very useful in maintaining the surface. With some rocks it is difficult to get enough fine material for use in the original construction.

333. Spreading the Stone. The stone is usually hauled from the crusher to the road in wagons or carts, dumped upon the roadway, and spread by forks or rakes. This practice is objectionable, since the coarse and fine fragments become separated in the process, producing a layer of unequal density and an irregular surface after rolling. It is sometimes specified that the stone shall be dumped upon a plank platform, from which it is distributed with shovels. This last method of spreading costs 4 to 6 cents

per cubic yard—about twice that by dumping and raking (see § 356)—and is appropriate only when the very best results are sought. Wagons are upon the market which automatically dump and distribute the stone in layers of uniform thickness, but owing to their cost and weight they are not in very general use. Some contractors use a road leveler to distribute the broken stone, for which purpose the Shuart grader, Fig. 62, has some marked

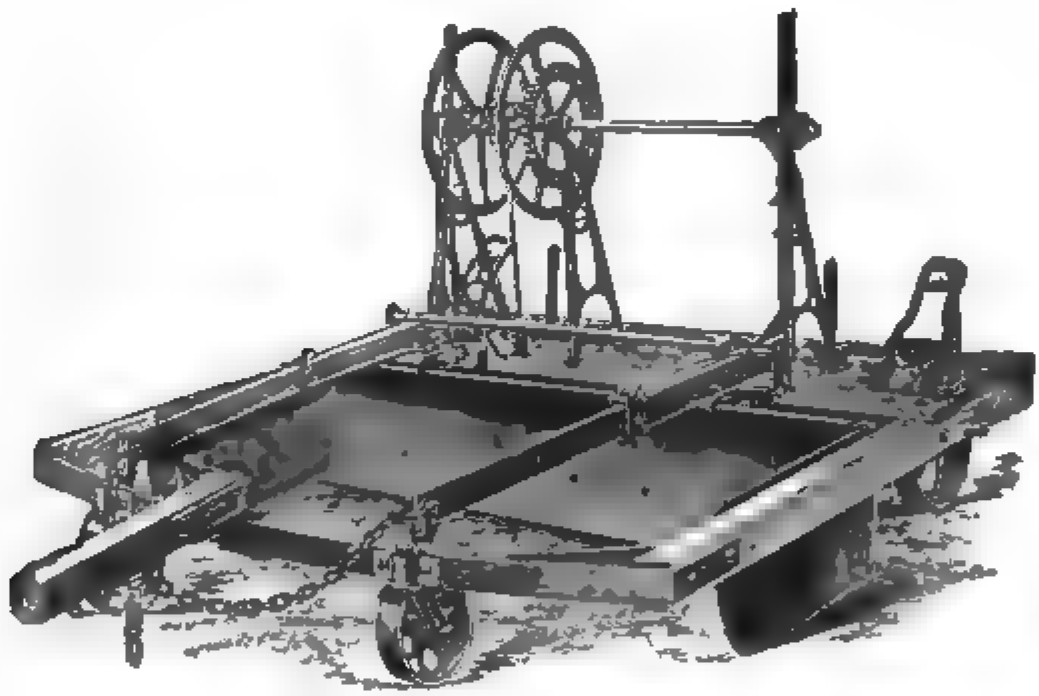

FIG. 62 – SHUART GRADER.

advantages. The blade can be set at any angle with the line of draft, and is adjustable in height. The guards at the ends of the blade can be swung entirely out of the way, and then the machine may be used to level or crown the subgrade.

The stone should be applied in uniform layers, the thickness of each depending upon the total thickness of the road. Two methods are in use for gaging the thickness of the layers of stone. 1. On the finished subgrade, wood cubes of a depth equal to the thickness of the layer are set at frequent intervals, and the loose stone is laid even with the tops of these blocks. This method is sometimes described as building by blocks, and is the one employed on the state-aid roads of New Jersey. 2. The soil is brought to an established grade, and the finished road is required to be brought to another established grade, in which case neither the absolute thickness nor the uniformity of the several courses is a

matter of much importance. This method is employed on the state-aid roads in Massachusetts.

334. Shrinkage in Rolling. Before beginning to spread the layers of stone, it is necessary to inquire as to the amount the crushed stone will shrink in rolling. The shrinkage has an important bearing upon the thickness and cost of the finished road; but the amount of shrinkage is often greatly over-estimated. It is frequently stated that rolling will cause broken stone to shrink 33 per cent; or, as it is usually put, 6 inches will roll down to 4. Apparently this statement is based upon MacAdam's experience; but MacAdam used neither a binding material nor a roller, and the road was compacted only after months of travel, when the traffic had pulverized sufficient material to bind the road and after much of that which had been pulverized had blown away. The following examples from actual practice show no such shrinkage.

In one case,* with trap rock 1½ to 2½ inches, rolled with a 12½-ton steam roller upon a subgrade so hard that the wagons hauling the stone made no ruts, 5.67 inches of loose stone rolled to 4 inches, and 7.38 inches rolled to 6 inches. The average thickness of the loose stone was determined by dividing the quantity of stone used by the area covered. The first is a shrinkage of 29 per cent and the second of 19 per cent. The difference between these two results is probably due to errors of observation, to variations in the thickness of the finished road, and to the fact that the thicker layers did not compact as solidly as the thinner ones. The stone was rolled dry until the desired thickness was reached, when the binder was added, and sprinkling was commenced.

In another case,† with 2-inch trap laid on the compact surface of an old crushed-stone road and rolled with a 12-ton roller, 3.9 inches of loose stone rolled to 3 inches. The shrinkage was 23 per cent. The thickness was determined from the area covered and the quantity of stone used. No stone could have been forced into the subgrade, but there was some uncertainty as to the average elevation of the surface of the old street.

It has been determined ‡ by tests over several miles of road

* W. C. Foster in Trans. Amer. Soc. of Civil Eng'rs, Vol. 41, p. 135–38.

† F. G. Cudworth in Trans. Amer. Soc. of Civil Eng'rs, Vol. 41, p. 126–28.

‡ H. P. Gillette in Economics of Road Construction, p. 19–20. New York, 1901.

where the output of the crusher was carefully measured in wagons and also when rolled in place, that 6 inches of loose hard limestone will roll down to $4\frac{3}{4}$ inches, which is a shrinkage of 20 per cent.

335. It is probable that the maximum *actual* shrinkage in rolling is less than 20 per cent. The *apparent* shrinkage depends upon the nature and condition of the subgrade, i. e., upon the amount of stone forced into the earth.

If the soil is *clay*, the sprinkling required to work the binder into the interstices may soften the subgrade so that considerable stone will be forced into the earth. This condition is indicated by the roller's leaving tracks upon the surface; and when this occurs, the work should be stopped until the subgrade dries out. To prevent the crushed stone from being forced into the clay subgrade during construction or after completion—particularly when the frost is going out,—a layer of sand, stone screenings, ashes, or the like, is sometimes interposed. The English engineers often use "hard core" (a mixture of brick rubbish, old plastering, and broken stone) on a clay soil, to prevent the mud's working into the metaling. Any material not affected by water is useful for this purpose; and the finer it is the better, since the smaller will be the apertures in it, and the more certainly will it prevent the soil from coming up through it.

If the soil is *sandy*, a thin layer of coarse gravel or broken stone laid upon the surface and then rolled, will prevent any further loss of the road metal in the subgrade. If the soil is nearly pure sand, the wetter it is the less crushed stone will be forced into it; and therefore if water is plentiful, it may be wise to keep the sand saturated while the rolling is in progress to prevent the loss of the stone. The Massachusetts Highway Commission used cotton cheese-cloth on a soft fine sand to prevent the stone from sinking into the subgrade. "It is not at all needful that the partition should be enduring, for as soon as the stones in the lower layer have been forced into contact and have become bound together, there is no further danger of the mingling of the stone with the sand; and hence the speedy decay of the fabric is a matter of no consequence. The cloth was spread in strips lengthwise of the way; and the stone for the bottom layer was shoveled from the sides upon it with no unusual care. A section through such a road shows that the stones do not

tear through the cloth. At 3 cents per square yard on the road, the cost of the cloth may be less than one third that due to the loss of the broken stone which would occur if it were allowed to come directly in contact with the sand. Various kinds of strong paper were tried, but found worthless."* "A thick coating of straw has been used to hold up the macadam on a sandy soil."†

However, if the sand is firm enough to hold up the stone during the rolling, it is not necessary to prevent the mixing of the sand and the stone, since the subgrade may be left a little high, with the expectation of forcing the stone into the sand. This is equivalent to using the sand of the subgrade as a filler or binder for the lower portion of the broken stone. If the sand is dry and nearly pure, it can be thus forced nearly to the top of a 4-inch course of coarse broken stone.

336. ROLLERS. The roller is indispensable for the economic construction of broken-stone roads. Roads can be built without the use of a roller, but always at large expense to the traffic and with great waste of the road metal; and such roads never have as smooth a surface and are not as durable as if a roller had been employed in their construction. With traffic-consolidated roads, much of the metal is worn round and smooth before the fragments become firmly fixed in place; and the dirt brought upon the road by the traffic mixes with the stone and prevents it from ever packing as solidly as the clean stone would, and, besides, the dirt when wet has a lubricating effect upon the stone which under the action of traffic causes the surface to break up readily. Further, during the time traffic is consolidating the stone, the surface is not even approximately water tight; and therefore the subgrade is softened by rains, and the stone is mixed with the earth below and virtually lost. Ordinarily, it is true economy to compact the road by the use of a roller.

Classified according to the power employed, there are two forms of rollers: the horse roller, and the steam roller. The horse roller was first introduced in France about 1834, and the steam roller in 1865. Neither MacAdam nor Telford used a roller in constructing roads, as it was invented after their time.

* Shaler's American Highways, p. 154–56.

† Gillette's Economics of Road Construction, p. 12.

337. Horse Rollers. There is a variety of horse rollers on the market. Fig. 63 shows the general form. Each consists essen-

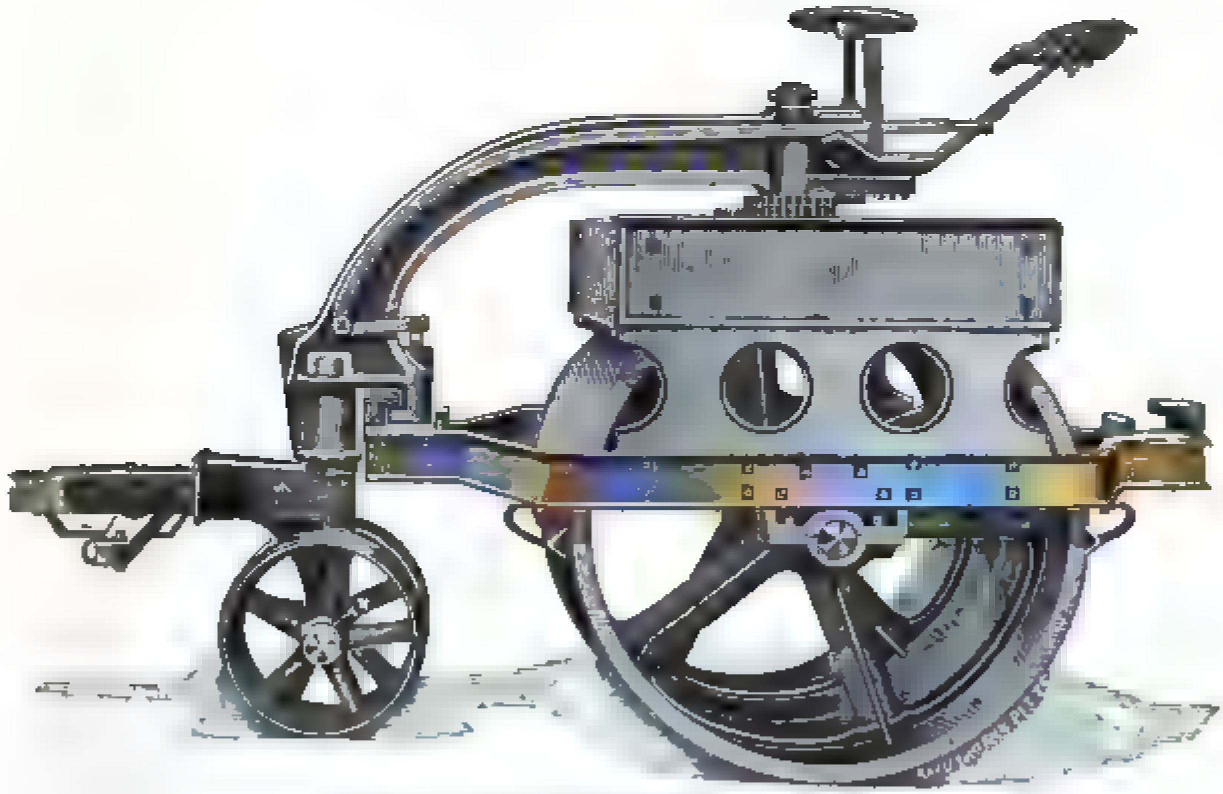

FIG. 63.—REVERSIBLE HORSE ROAD ROLLER.

tially of a hollow cast-iron cylinder 4 to 5 feet long, 5 to 6 feet in diameter, and weighing from 3 to 6 tons. Some forms are provided with boxes in which stone or iron may be placed to increase the weight, and some have closed ends and may be filled with water or sand. Most makers provide a scraper for keeping the roller clean, and also a brake for controlling the motion on a down grade. In the better forms, the direction of the motion is reversed simply by swinging the tongue around the machine. The lighter rollers are drawn by two horses and the heavier by four. The weight per linear inch of face varies from 200 to 300 pounds.

The catalogue price of horse rollers is usually about $100 per ton.

338. Steam Rollers. There are two type forms of steam rollers, as shown in Fig. 64 and 65, pages 224–25. The first is the form commonly used in constructing broken-stone roads, and is usually called simply a steam roller. The second is the form employed in rolling asphalt pavements, and is often called an asphalt roller, and also a Lindelof roller—after the original inventor.

The steam stone-road roller, Fig. 64, is made by a number of manufacturers, but all are practically the same. The total weight

varies from 10 to 20 tons, and the pressure under the drivers varies from 450 to 650 pounds per linear inch. The cost of these rollers is usually about $200 to $225 per ton.

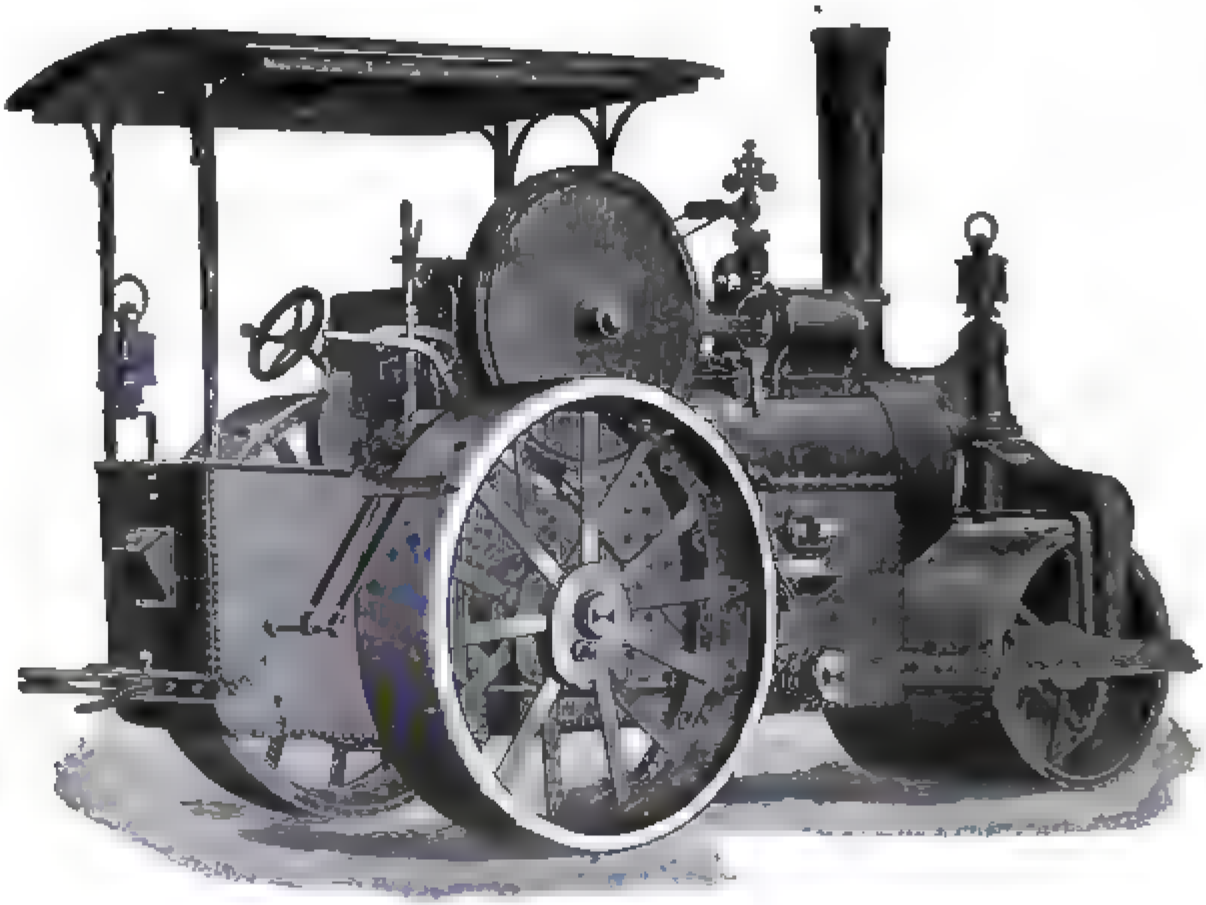

FIG. 64.—STEAM STONE-ROAD ROLLER.

There has recently been introduced a type of traction engine, the wheels of which may be replaced by heavy rollers, thus converting the traction engine into a road roller of moderate weight. The rolls cost $200 to $300 in addition to the price of the engine. A machine of this kind would be valuable as a substitute for a road roller where the amount of work will not justify the purchase of a steam roller and where the traction engine could be employed part of the time for other purposes.

The asphalt roller. Fig. 65, page 225, differs from the preceding form chiefly in being lighter and in being so arranged that the front and rear rolls cover the same space. The rear roller may be filled with water or sand. The main purpose of this roller is to smooth rather than to compress, but it can be used for stone-road construction. The weight varies from 3 to 15 tons. 5 tons being the usual weight. The pressure under the front roll is usually about

200 pounds per linear inch of face, and that under the rear roll can be varied between 200 to 260 pounds per linear inch of face.

339. It is desirable that the weight of the roller should be proportional to the hardness of the stone, as too great a weight crushes the material instead of compacting it. An excessively heavy roller will sometimes sink into light or loose soil, and force it ahead in a wave which the roller can not surmount. This may sometimes

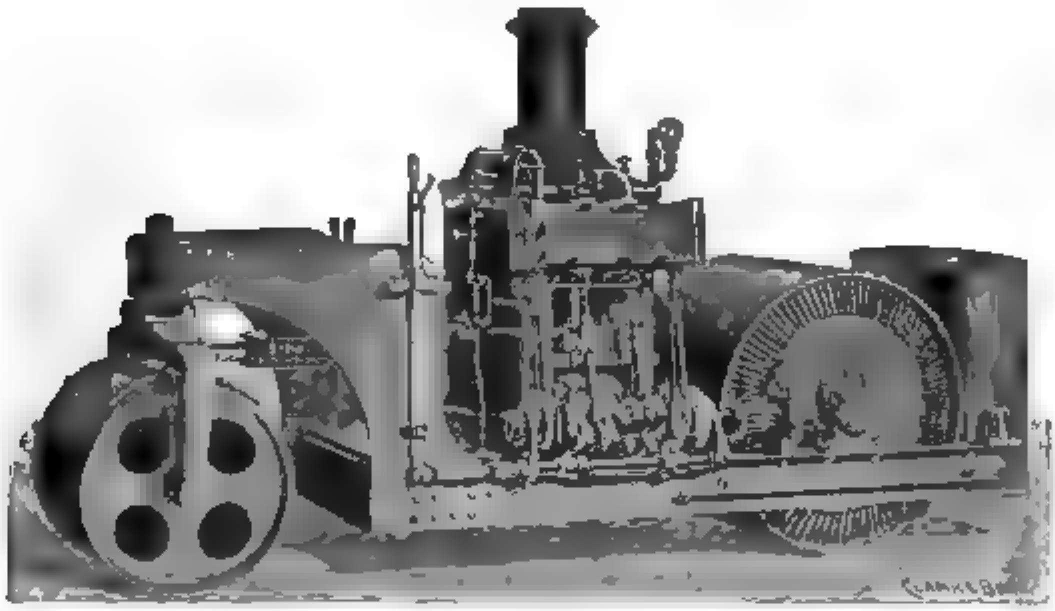

FIG. 66.—ASPHALT ROLLER.

be prevented by spreading a thin layer of sand or gravel on the surface being rolled. A similar difficulty sometimes occurs with a heavy roller on a layer of loose stones. If the front wheels or rollers of the machine were larger, this difficulty would be decreased. In localities where the soil is of a loose sandy nature, a roller weighing 10 or 12 tons is usually preferred; and in districts where the soil is gravelly or stiff clay, a weight of 12 or 15 tons is used. In localities where the road material is hard, a 15-ton roller is necessary; but with the softer stones a weight of 10 or 12 tons is sufficient.

340. Horse vs. Steam Rollers. There was once considerable discussion as to the relative merits of the horse and the steam roller, but it is now settled that a steam roller is indispensable for the construction of the best stone roads. The horse roller is the cheaper in first cost, is lighter, and is generally cheaper to operate; but on account of its lighter weight it is less effective on soft material

than the steam roller, and can not thoroughly compact the harder road materials, and, besides, the horses' feet often loosen the material nearly as fast as it is packed down by the roller. The time required to consolidate a stone road varies with the weight of the roller, and for this reason roads can be built more quickly with the steam than with the horse roller.

For compacting the subgrade of roads and pavements, the horse roller is reasonably effective. However, there is one important advantage in using the steam roller to consolidate the subgrade of a street pavement: One of the chief objects in rolling the foundation is to discover partially filled trenches, which usually run both lengthwise and crosswise of the street; and therefore the roller should be run over the street both longitudinally and transversely. The latter can be done only with a steam roller.

341. ROLLING THE STONE. Rolling is a very important part of the construction of a broken-stone road. The subgrade should be rolled to prevent the stone from being forced into the earth. The lower course of the stone should be rolled to compact it, so that the pieces will not move one upon the other under the traffic; and the top course should be rolled to pack or bind the pieces into place, to prevent their being knocked out by the horses' feet. Rolling accompanied by sprinkling is necessary also to work the binding material into the interstices so as to make the surface water-tight. Roads that have been consolidated by traffic are largely held together by mud, and after long use are fairly smooth and hard in dry weather, but soon become soft and muddy during a wet time.

The stone is put on in two or three layers,—according to the total thickness of the finished road,—and each course is thoroughly rolled before the next is added. The courses should not be more than 4 to 6 inches thick. When a telford foundation is used, broken stone is spread over the pavement to bring the top surface to the proper form and height, after which it is rolled.

342. The rolling should proceed gradually from both sides toward the center. If the weight of the roller can be varied, commence with the unballasted roller, and increase the weight as the stone becomes consolidated. If the surface of the layer shows a wavy motion after being rolled three or four times, the subgrade

is too wet, and time should be given it to dry out. Some coarse brittle granitic rocks begin to crawl and the sharp edges to break off after the roller has passed over them a few times; but a light sprinkling of sand or stone screenings will prevent this, and facilitate the consolidation of the layer. All irregularities of the surface developed by the rolling should be corrected by filling the depressions with stone of the size used in the layer.

The rolling should be continued until the stone ceases to creep in front of the roller, and until the macadam is firm under the foot as one walks over it. When the rolling is complete, one of the larger stones of the course can be crushed under the roller without indenting the surface of the layer.

When the first course has been consolidated, a second, usually a thinner one of smaller stones, is added, and then rolled the same as the first. Finally a third course consisting of about half an inch of sand or fine stone and stone dust is added. The roller is then passed over this layer, with the result that the bits are ground to powder. As the rolling of this course proceeds it is sprinkled, the aim of the sprinkling and rolling being to work the fine material into the cavities between the pieces of crushed stone, thus binding the whole into a solid mass. The proper binding of the road is the most important part of the construction, and will be more fully considered presently (see § 345).

343. Amount of Rolling. The total amount of rolling required varies with the weight of the roller, the hardness and the size of the stone, and the amount of binder and water used. Trap rock being very hard requires two or three times as much rolling as most other stone. An excess of binding material and of water gives a compact surface with comparatively little rolling, but the road is not as durable as though it had been more thoroughly rolled.

In New York City, 5 inches of crushed gneiss on telford and 5 inches of trap on the gneiss, bound with trap screenings, was rolled with a 15-ton steam roller at the rate of 40.6 sq. yd. per hour, or 10 cu. yd. per hour. Although it is common to give the amount of rolling in terms of the time required, the statement is somewhat indefinite, since the work accomplished varies with the speed of the roller and also with the length of run, i. e., with the time lost

in starting and stopping. The usual speed of steam rollers is 2 to 2½ miles per hour. The above work is equivalent to 0.553 ton-miles per sq. yd., or 2.246 ton-miles per cubic yard. The number of trips was 130.*

In making repairs, a 6-inch course of 2-inch trap was rolled at the rate of 26.2 sq. yd. per hour, or 4.4 cu. yd. per hour. The work amounted to about 0.859 ton-miles per sq. yd., or 5.177 ton-miles per cu. yd. The number of trips over the surface was 201.†

An area of 22,000 square yards of a 3-inch course of 2-inch trap upon an old broken-stone road, bound with trap-rock screenings and rolled with a 10-ton steam roller, was finished at an average rate of 47.15 sq. yd. per hour of rolling, the extremes being 38.4 and 61.1 sq. yd. per hour. This was an average of about 4.0 cu. yd. per hour.‡

A 6-inch course of 1⅛ to 2¼-inch trap rock, bound with limestone screenings, was rolled with a 12½-ton steam roller at an average rate of 31.4 sq. yd. per hour, or 5.2 cu. yd. per hour.§

The Hudson County Boulevard (Jersey City, N. J.) consists of 8 inches of telford, 2½ inches of 2½-inch stone, 1½ inches of 1½-inch stone, and then ½ to 1 inch of coarse screenings—all trap rock. The macadam top was supposed to roll down to 4 inches, i. e., 4½ to 5 inches of loose stone was supposed to roll to 4 inches. The rolling was distributed about as follows: On the telford, 10 to 12 passages; on the 2½-inch course, 8 to 10 passages; on the 1½-inch course, 10 to 12; and on the screenings, 80 to 90,—making a total of 100 to 120 passages of the roller over the road.

344. The above examples are representative of American practice in building the best crushed-stone roads, and represent considerably more rolling than is customary in either England or France. In Paris the porphyry roadways with courses from 3 to 4 inches thick receive from 0.234 to 0.41 ton-miles per sq. yd., or 2.99 to 3.78 ton-miles per cu. yd.‖ The number of passages of the roller varies from 75 to 100. In Paris some streets were "thrown open

* Trans. Amer. Soc. Civil Eng'rs, Vol. 8, p. 105–6.

† *Ibid.*, p. 107.

‡ *Ibid.*, Vol. 41, p. 127.

§ *Ibid.*, p. 138.

‖ *Ibid.*, Vol. 8, p. 104.

to traffic when the rolling had reached about the point when in this country the application of screenings would commence." * It is believed that the American roads are enough better to pay for the greater amount of rolling they receive. As a rule, American crushed-stone roads are better constructed than those in Europe, notwithstanding the fact that the European roads are frequently cited as models for imitation in America. The superiority of American roads is partly due to the greater amount of rolling they receive, and partly to the greater quantity and better quality of binding material used. As a rule the broken-stone roads are better maintained in Europe than in America—probably because of the cheaper hand labor.

345. BINDING THE ROAD. The interstices between the fragments of stone should be filled with a fine material which will act mechanically to keep out the rain water and thereby keep the subgrade dry, and also to support the fragments and prevent them from being broken, and which will act physically and possibly also chemically to bind or cement the fragments into a single more or less solid mass. The proper binding of the stone is the most important part of the construction of a broken-stone road.

The material employed to fill the interstices in a broken-stone road is usually called the binder, and sometimes the filler.

346. Nature of the Binder. The binding material or the filler should be finely divided so as to be easily worked into the interstices, should have a considerable resistance to crushing so as to properly support the pieces of crushed stone; and should not change its physical condition when wet. Various materials have been employed—clay, loam, shale, sand, and limestone and trap-rock screenings.

Clay and loam are frequently used. Their merit is that they are cheap, are easily applied, and have a high cementing power (see Table 20, page 187); but they are easily affected by water and frost, and when wet act more as a lubricant than as a binder. Clay or loam binder will give a smooth road without much rolling, but such a road is liable to be very dusty in dry weather, and muddy

* Trans. Amer. Soc. Civil Eng'rs, Vol. 8, p. 105.

in wet weather. When clay or loam is employed as a binder, the utmost care should be taken that no more is used than just enough to fill the voids.

Shale and slate are only hard and compact clay, and their only merit is that they give a smooth surface with but little rolling. They are speedily reduced to dust, and then have all the disadvantages of clay. They have fair cementing power—see Table 20, page 187.

Sand is often used as a filler, and if composed of fine, clean, hard grains, gives fair results; but sand which is resistant enough for a good binding material usually consists of silica or quartz, neither of which has a high cementing power (Table 19 and 20, page 186). If the grains are coated more or less with iron oxide, or if accompanied by bits of ironstone (clay cemented with iron oxide), sand makes an excellent binding material, since the iron possesses considerable cementing power. This form of binder is particularly valuable in making repairs over an opening when a roller is not available, or when water for washing in the binder is scarce. Low-grade iron ore has been used for a binder—either alone or mixed with stone dust.

Fine screenings—the finest product of the stone crusher, say, from ½ or ¼ inch to dust—from the stone used in the body of the course is the most desirable material for a binder, partly because it helps to utilize the entire product of the crusher, partly because of its high crushing strength, and partly because the stone is usually selected for the high cementing power of its dust. Limestone has very high cementing power, but is soft and pliable. Trap has a fair cementing power, and is hard and durable. Limestone screenings require less rolling, but the trap dust makes a more durable road.

Sometimes the detritus removed from the surface of a stone road during maintenance or preparatory to making repairs, is employed as a binder. At best, such material is very poor for this purpose. It is worn out and has performed its duty; and, besides, it is composed largely of manure and vegetable and earthy matter—all of which are very undesirable in a binder. Such detritus is more valuable as a fertilizer than as a road material.

347. Applying the Binder. There is a difference of opinion

among competent engineers as to the best method of applying the binding material. Some apply it on the top of each course, and some on top of only the last course. In the first case, all the voids from the bottom to the top of the road are filled with fine material; in the second case, the binder usually fills the voids of the top course only. Those who advocate the first method claim that the whole mass should be filled to prevent the stones from moving under the traffic, and also to prevent the soil from working up from below; while the advocates of the second method claim (1) that filling the top layer is sufficient to hold the stone in place near the surface, (2) that the stones of the lower courses have no tendency to move, (3) that the unfilled voids of the lower course promote drainage, and (4) that as the upper layer wears away, the dust will wash down into the lower open spaces in such a manner as always to keep the 3 or 4 inches just below the surface properly bound. If the stone is hard, or if the lower courses are not thoroughly rolled, applying the binding material only on the top of the last course practically fills the voids to the earth foundation; but of course it is cheaper to apply the filler on the top of each course than to attempt to fill all of the voids by applying it on the top course only. If the stone in the lower courses is soft, or if the top of the next to the last course is thoroughly rolled, applying the binder on the top fills the voids in the top course only. It is sufficient to fill the voids of the top course.

The binder is applied by spreading a layer of "fines" about half an inch thick over the partially rolled surface. The filler should be dumped upon a board platform, and not directly upon the road surface; and should be distributed evenly over the stone with a shovel. Under no consideration should loam or vegetable matter be allowed to contaminate the stone screenings. After the binding material has been evenly distributed, the surface is then sprinkled and rolled. The sprinkler should have many fine openings, the object being to give a gentle shower rather than a violent flooding. The water washes the fine material into the cavities below, and the roller crushes the small fragments and makes more dust. The rolling also aids in working the binder into the mass; in fact, the binder can be worked in to a considerable extent by dry rolling, and consequently the quantity of water used varies widely with

the method of doing the work, but is usually about 4 to 6 cubic feet per cubic yard of stone. Sometimes men with heavy brooms are kept upon the road sweeping the binding material about to assist in working it in, and also to secure a more uniform distribution of it. While applying the screenings care should be taken to pick off any coarse stone—particularly flat ones,—as they do not bind well and their subsequent loosening causes the road to ravel (§ 377).

As the rolling and sprinkling proceed, fine material should be added where needed, i. e., as open spaces appear. All the filler should not be put on in the beginning, since a thin layer can be worked in to better advantage than a thick one; and, besides, it is desirable to use only enough to fill the voids.

Occasionally the surface of the road becomes muddy and sticks to the roller. This can be remedied in either of two ways: viz., by sprinkling the roller and keeping it constantly wet, or by keeping the sprinkling wagon immediately in front of the roller and having the binder always fully saturated. The rolling is continued until the water is forced as a wave in front of the roller and until the surface behind the roller is mottled or puddled and is covered with a thin paste. The binding, or the puddling of the surface, can not be done satisfactorily when the surface freezes nightly.

When finished, if the road is allowed to dry and is then swept clean, the surface will be seen to have the appearance of a rude mosaic, the flat faces of the fragments of stone being crowded against one another and the interspaces being filled with the binding material—the latter occupying about half of the area. Such a surface when dry will stand considerable sweeping with a steel broom or brush without the fragments of stone being loosened. The water used in construction not only aids in working the binder into the interstices, but also develops the cementing power of the rock dust.

348. Usually after the rolling has been completed a thin coating of binding material is sprinkled over the surface. Authorities differ as to the amount of fine material to be left on the finished surface, some specifying as little as ⅛ inch and some as much as 1 inch, the usual quantity being ⅜ to ½ inch. If only enough binding material to fill the interstices between the coarser fragments is left

upon the road, the fine material will be blown and washed away, and soon there will not be enough to level up between the large bits and to hold the surface stones in place, when the wear will come directly upon the stones. On the other hand, if any considerable quantity of fine material is left upon the surface, it is speedily ground up, and becomes offensive dust if it is not sprinkled, and equally objectionable mud if it is sprinkled. It is probably best to put on a quantity just sufficient to give a thin layer, say, $\frac{1}{2}$ to $\frac{3}{4}$ inch, over the surface, and when this amount is blown or washed away renew it. By this method, the wear on the body of the road will be prevented, a minimum amount of sprinkling will be required, and there will be as little dust as possible. The surface coat is also serviceable in decreasing the tendency of the binding material to dry out and to lose part at least of its cementing power; i. e., the surface coat is serviceable to prevent the raveling of the road (see § 377). Fine material over and above that required to fill the interstices is useful only to prevent raveling and to keep the wear from the surface of the stone; and therefore sand is as good for the top dressing as stone dust, and is usually much cheaper. Loam or clay does fairly well for a top dressing, but it readily grinds to dust and blows away when dry, and when wet makes mud. It is desirable that this coat of fine material shall be sprinkled and rolled before the traffic is admitted.

The road is now finished; and after it has dried out for a day or two, it may be thrown open to traffic.

349. Amount of Binder. The amount of binder required depends upon the hardness of the stone and the amount of rolling preceding the application of the binder (see § 347). The voids in the broken stone can be reduced by rolling to 20 or 25 per cent, say 22 per cent, of the compacted mass;* and the completed road will contain 4 to 7 per cent, say 5 per cent, of voids;† and therefore enough binder must be added to fill about 17 ($=22-5$) per cent of voids. The binder itself usually contains 40 to 50 per cent of voids, and therefore the volume of filler required is 40 to 50 per cent more

* Codrington's Maintenance of Macadam Roads, p. 25 and 52. London, 1870.

† H. P. Gillette in Economics of Road Construction, p. 19 and 32, and M. Léon Durand-Claye, Engineer-in-Chief, Department of Roads and Bridges, France, in *Annales des Ponts et Chaussées*, as quoted in *Engineering Record*, Vol. 25, p. 232.

than the voids to be filled, i. e., 40 to 50 per cent more than 17 per cent of the original volume of stone; or, in other words, the amount of filler required is 25 to 35 per cent of the thickness filled. This allows a little for waste and for the thin coating spread upon the finished surface. If the binder is applied before the rolling has progressed very far, more fine material will be required, since some of it will work in between the fragments of stone and prevent them from coming into as close contact as they otherwise would. In this case, part of the surplus binder will be flushed to the surface during the sprinkling and rolling, as mortar flushes to the surface in tamping concrete; but in no case does all the surplus thus work out, and consequently the road is not as durable as though only enough binder had been used to fill the voids; and, farther, the binder which flushes to the surface must be removed as mud. An excess of binder is often used to reduce the cost of construction by decreasing the amount of sprinkling and rolling required; but such a practice adds to the cost of maintenance, and the road is less durable and more dirty.

350. COST OF CONSTRUCTION. The cost of construction of a crushed-stone road varies greatly with the size of the job, the conditions of the material and labor markets, the specifications under which the work is done, etc.; and any general statements must be considered only as approximate for any particular case.

351. Cost of Quarrying. The cost of quarrying will vary with the amount of stripping, the hardness of the rock, the depth of face, the method of quarrying (hand tools or explosives), the method of drilling (hand or power), etc. For hard limestone, the cost of quarrying, exclusive of quarry rent, pumping, and superintendence, was as in Table 21, page 235.

Table 22, page 235, gives the detailed cost of quarrying road stone in Great Britain. Wages were probably less than in America, and probably the labor was correspondingly less efficient. In quarry No. 1, the rock was "highly siliceous and very seamy in parts, 60 per cent being very hard and solid." In No. 2, the rock was "hard and tough, and seamy in places." No. 3 was a "hard and very tough basalt."

For additional data on the cost of quarrying, see the first part of Table 23, page 237.

TABLE 21.

COST OF QUARRYING HARD LIMESTONE EXCLUSIVE OF QUARRY RENT, PUMPING, AND SUPERINTENDENCE.*

Results in Cents per Cubic Yard.

Ref. No.	Items of Expense.	Depth of Drill Holes, Feet.							
		1	2	3	4	6	8	10	12
1	Dynamite	26	18	15	13	11	9	8	7
2	Drilling	66	32	22	17	10	9	7	6
3	Cost of quarrying, — solid stone	92	50	37	30	21	18	15	13
4	Cost of quarrying, — loose stone	92	45	30	23	15	13	9	8
5	Sledging and throwing back from quarry face	15	15	15	15	15	15	15	15
6	Total cost	107	60	45	38	30	28	24	23

* Gillette's Economics of Road Construction, p. 26.

TABLE 22.

ACTUAL COST OF QUARRYING ROAD STONE.†

Cents per Ton (2,000 pounds).

Ref. No.	Items.	Quarry.		
		No. 1.	No. 2.	No. 3.
1	Stripping	4.1	1.4	1.0
2	Drilling—hire of engine, coal, water, dressing drill-bits, depreciation of drill, etc.	3.6	2.7	3.3
3	Blasting—dynamite, detonators, wire and wiring, charging and tamping	1.9	2.1	2.3
4	Sledging to size for 9″ × 16″ breaker	5.5	5.4	6.5
	Total	15.1	11.6	13.1
5	Number of tons quarried	4 158	3 475	2 102
6	Height of vertical face, feet	33	22	18

† Road Making and Maintenance, Thomas Aitken, p. 170–72. London, 1900.

352. Cost of Setting Telford. The cost of setting a telford foundation will vary greatly with the character of the stone and with the amount of knapping and wedging done. If the foundation stones are laminated, they will fit well one against the other, and consequently require comparatively little wedging, but if the stone is unstratified and breaks in irregular pieces, more labor will be required to place it and to break off projecting points and to wedge the stones. On the Hudson County Boulevard (Jersey City, N. J.) three men set, dressed, and thoroughly wedged about 3 square yards of trap telford foundation per hour, the stone being wheeled from the side, at a total cost for labor of about 15 to 18 cents per square yard. With a soft, bedded stone, the cost is only about 5 to 6 cents per square yard.

On the state-aid roads in Massachusetts, in 1899 the average contract price for a 6-inch telford foundation in place was 34 cents per sq. yd., the minimum being 30 cents and the maximum 50.*

353. Cost of Crushing. The cost of crushing varies with the amount of the output, the arrangement of the plant (§ 330), the hardness of the stone, the price of labor and supplies, etc. Table 23, page 237, gives the details for four kinds of stone. Notice that for the ledge stone, the output was 80 to 100 cubic yards per day, and the cost of crushing was 20 and 21 cents respectively. If the output is decreased, the price will be slightly increased, and vice versa. A study of numerous data seems to show that the above is fairly representative, except that frequently the prices paid for labor are less.

354. Price of Crushed Stone. Crushed limestone is occasionally sold f.o.b. at the quarry as low as 35 to 40 cents per ton (about 47 to 53 cents per cu. yd.),† and frequently as low as 45 to 50 cents per ton (60 to 65 cents per cubic yard). The cost of crushed trap f.o.b. at the quarries in New Jersey, for several years previous to 1900, was 40 to 50 cents per ton; but in that year it was increased nearly 50 per cent.‡ In Massachusetts, the cost of broken trap varies from $1.10 to $1.60 per ton (about $1.47 to $2.13 per cu. yd.)

* Report of Massachusetts Highway Commission for 1900 p. 106-09.

† A cubic yard of screened limestone is usually considered as weighing 2,600 or 2,650 pounds.

‡ Report of New Jersey Commissioner of Public Roads, 1900, p. 43.

TABLE 23.

DETAILED COST OF CRUSHING STONE.*

Cents per Cubic Yard.

Ref. No.	Items.	Greenish Trap Ledge Stone.	Conglomerate Ledge Stone.	Cobble Stone largely Trap.	Cobble Stone largely Granite.
1	Labor drilling—steam	9.2	....	....	....
2	" " hand	....	24.9	....	....
3	Coal, oil, waste, repairs, and powder	8.4	1.8	....	....
4	Sharpening drills and tools	6.9	2.3	....	....
5	Breaking stone for crusher	27.9	42.0	....	....
6	Cost of preparing for crusher	52.5	71.0	....	....
7	Filling carts	9.8	12.7	....	14.4
8	Hauling to crusher	7.2	6.2	31.4	9.8
9	Cost of delivering to crusher	17.0	18.9	31.4	24.2
10	Feeding crusher	5.3	5.3	3.3	6.5
11	Engineer for crusher	3.1	3.8	2.9	3.6
12	Coal, oil, waste, and repairs	7.9	5.0	4.5	4.4
13	Repairs	4.1	....	....	1.1
14	Moving and setting up crusher	....	2.3	....	1.9
15	Watchman	....	4.9	2.4	2.9
16	Cost of crushing	20.4	21.3	13.1	20.4
17	" " preparing for crusher	52.5	71.0	....	....
18	" " delivering to crusher	17.0	18.9	31.4	24.2
19	" " crushed stone in bin	89.8	111.2	44.5	44.6
20	Cost of crushing stone per ton (2 000 lb.)	$0.74	$0.88	$0.33	$0.33
21	Total amount crushed, tons	3 805	1 620	1 587	2 399
22	Tons crushed per hour	9.0	11.2	15.7	12.1
	Prices paid above				
23	Foreman, per day of 9 hours	$3.00	$3.00	$3.00	$3.00
24	Operator of steam drill	2.40	2.50	....	....
25	Stoker for steam-drill boiler	1.25	....	....	....
26	Engineer for stone crusher	2.00	2.25	2.00	3.00
27	Blacksmith	2.50	2.25	....	....
28	Watchman	....	1.75	1.75	1.75
29	Common labor	1.75	1.50	1.50	1.75
30	Water boy	....	1.00	1.25	....
31	One driver and two 1-horse carts	5.00	5.00	5.00	5.00
32	Coal—anthracite, per 2 000 lb	5.25	5.25	5.25	5.25
33	Powder, per box of 50 lb.	11.34	11.34	....	....

* A. F. Noyes, City Engineer of Newton, Mass., in Report of Massachusetts Highway Commission for 1898, p. 93–107.

on cars at the end of the railroad transportation.* In Boston, the cost of crushed granite delivered on the streets is $1.65 to $1.90 per ton. In Montreal, syenite macadam delivered on the street costs an average of $1.15 to $1.20 per ton.

355. Cost of Hauling. We will assume that the wages of driver and team is 30 cents per hour, although in cities it will usually be more than this. A load will vary from 1 to 1½ cubic yards, the former on soft roads and the latter with good ones; and we will assume that 1¼ yards is an average load. When the stone is stored in bins, it will require about 5 minutes to load; and an equal time will be consumed in dumping. The cost of the time consumed in loading and unloading, then, is one sixth of the hourly wages of the team and driver, or 5 cents per load, which is equal to four cents per cubic yard. The team can easily travel 2½ miles per hour, or 220 feet per minute; but to allow for little delays, we will assume that the team averages 100 feet and return per minute, at a cost of 0.5 cents per load or 0.4 cents per cubic yard. The cost of hauling, then, is 4 cents for loading and dumping *plus* 0.4 cent per 100 feet of distance hauled. This is equivalent to 25 cents for a haul of 1 mile.

356. Cost of Spreading. The cost of spreading will depend upon whether it is dumped upon a wood platform and spread by hand, or upon the road and spread with a road grader (§ 333). The average cost of the first process on state-aid roads in Massachusetts is 4 cents per ton or 6 cents per cubic yard; † while with a road grader the cost of spreading is about 2 cents per cubic yard, including the hand labor in completing the leveling.‡

357. Cost of Sprinkling. The cost of sprinkling is an extremely variable item, depending upon the source of the water supply and the nature of the subgrade. It will require at least 4, and possibly 16, cubic feet of water per cubic yard of stone. "One man with a good hand pump will raise 1,000 cu. ft. of water 16 ft. high in 10 hours into a tank from which it can be drawn off into the sprinklers. If the product of two good portable crushers is going into the road, it will take about 300 cu. ft. of water daily to

* Report of Massachusetts Highway Commission, 1901, p. 16.

† *Ibid.*, 1894, p. 30.

‡ Gillette's Economics of Road Construction, p. 29.

puddle the macadam and an equal amount to keep the subgrade in compact condition, although in very sandy soil twice as much water may be needed. One man will therefore pump enough water for 80 cu. yds. of crushed stone and for the subgrade, at a cost of 2 cts. per cu. yd. of stone. A sprinkler holding 60 cu. ft. of water is ordinarily used, which at $4 per day for team, cart, and driver will supply all the water needed, up to a haul of 1½ miles from the storage tank. A sprinkler can be loaded in ten minutes, and with the speed of team at 220 ft. a minute, or 2½ miles an hour, it is easy to estimate the number of trips a day and the number of sprinklers that will be needed for different lengths of haul. Ordinarily one sprinkler is required for each roller, so that the cost of sprinkling will be 10 cents per cu. yd., which, added to the cost of pumping, makes a total of 12 cts. per cu. yd. of stone; but with a long haul in sandy soil the cost frequently runs as high as 20 cts. per cu. yd." *

358. Cost of Rolling. The amount of rolling varies greatly with the amount and character of the filler employed (§ 346–49), and consequently there is a very great difference in the cost for different cases. Unfortunately the published reports upon the cost of rolling are very meager, and seldom fully state the items of expense included; and some are based upon time, some upon area, and others upon quantity with little or no data as to the thickness of the course, the kind of stone, the character of binder, etc. The actual daily expenditures for operating the roller vary with the cost of labor, coal, water, etc.; and the total daily cost of operation depends upon the amount of work done per season, i. e., upon the number of days over which the cost of interest, storage, and depreciation is to be distributed.

On Massachusetts state-aid roads, in 1894,† seven towns owning steam-road rollers (mostly 12-ton) ran them at an average daily cost of $5.42, the maximum being $6.46 and the minimum $3.72; and ten towns using hired rollers (mostly 12-ton) ran them at an average daily expense of $15.94, the maximum being $24.46 and the minimum $6.62. The cost for the first-mentioned towns probably does not include interest, storage, and depreciation;

* Gillette's Economics of Road Construction, p. 31.

† Report of Massachusetts Highway Commission for 1895, p. 40–41.

while that for the second, included these items and doubtless also transportation expenses and profits. In the towns owning their rollers, the average cost of rolling was 13.71 cents per cubic yard, or 4.05 cents per square yard; and the average amount rolled per day was 59 cubic yards, the maximum being 102 and the minimum 14. In the towns hiring rollers, the average price was 25.1 cents per cubic yard, or 8.8 cents per square yard; and the average amount rolled per day was 71 cubic yards, the maximum being 139 and the minimum 31.

359. Cost of Finished Road. The total cost of the road varies with the amount of grading and drainage required, the length improved in a single season, the length of railroad and wagon haul, the specifications, etc.

360. *New Jersey.* In northern New Jersey, the total cost of trap macadam roads 4 to 6 inches deep, where the rock was obtained near the road, ranged from 20 to 45 cents per square yard; and telford roads consisting of 8 inches of telford and two courses of broken stone 2½ and 1½ inches thick respectively, cost from $1.02 to $1.29 per square yard. In the southern part of that state, where the stone is transported 20 to 70 miles, 8-inch trap macadam roads cost from 23 to 70 cents per square yard, the average being from 50 to 60 cents per square yard.*

361. *Massachusetts.* The average cost of 220 miles of state-aid roads in Massachusetts built from 1894 to 1899,† reduced to the equivalent cost of a "standard mile" (15 feet wide), was $9,931.23 per mile for construction and engineering expenses, exclusive of cost of administration and the salaries of the chief engineer and two assistants. The maximum average for the roads in any township was $20,257.48 and the minimum $4,871.30 per "standard mile." The above gives an average cost of $1.126 per square yard, a maximum of $2.302, and a minimum of $0.564.

In Massachusetts in 1897, 52 miles were built in 187 towns (townships), the average cost of the several items being as shown in Table 24, page 241.‡ An examination of the reports for other

* Compiled from the Reports of the State Commissioner of Highways of New Jersey, 1895–1900.

† Report of Massachusetts Highway Commission, 1900, p. 150–57.

‡ *Ibid.*, 1898, Appendix C, p. 74–75.

years indicates that the above exhibit is fairly representative, except that the expenditure for stone is smaller than the average. In the state-aid roads built from 1894 to 1899, the cost of the broken stone was equal to 55 per cent of the total cost of the road, but in later years the amount of stone used was decreased.

TABLE 24.

COST OF MASSACHUSETTS STATE-AID STONE ROADS.

Items of Expense.	Per Cent of Total Cost.
Earthwork at 32.1 cents per cubic yard	16.4
Rock excavation at $1.80 per cubic yard	2.0
Shaping earth subgrade at 2.0 cents per cubic yard	2.4
Gravel for foundation and wings at 55.8 cents per cubic yard	3.5
Telford foundation at 33.9 cents per square yard	0.2
Broken stone at { $1.503 per ton for local stone; $1.920 per ton for trap }	45.3
Side drains at 34.5 cents per lineal foot	2.7
Rubble masonry—dry, at $3.133 per cubic yard	2.6
" " in cement, at $5.770 per cubic yard	3.3
Guard rails at 16 cents per lineal foot	1.7
Stone boundary-posts at $1.417 each	0.6
Paved cobble gutters at 66.0 cents per square yard	1.1
Vitrified-clay pipe-culverts—12-inch, at 65 cents per lineal foot	1.2
Land damages, catch basins, and minor items of construction	3.0
Engineering and inspection	14.0
Total	100.0

362. *New York.* In the State of New York in 1898, 22 miles of state-aid macadam roads were built in six sections, with an average cost of 84.0 cents per square yard, the maximum being $1.085 and the minimum 64.8 cents. The roads consisted of 4 inches of native stone, and 2 inches of trap rock bound with limestone screenings.*

ART. 3. MAINTENANCE.

363. After the road has been properly rolled and the surface has been made compact and smooth, it is very desirable that it should always be maintained in that condition. Many seem to believe that a stone road is a permanent construction which needs

* Report of New York State Engineer and Surveyor, 1899, p. 37.

no attention after completion; but proper maintenance is as important as good construction. The finest roads are the result of good construction and a system of maintenance whereby every defect is corrected before it has time to cause serious damage.

364. Agents of Destruction. A broken-stone road is a delicately balanced construction, and is peculiarly open to the destructive action of the traffic and the weather. A careful study of the various agents of destruction is necessary to a thorough understanding of the best methods of construction and maintenance.

The effect of narrow tires, equal-length axles, small wheels, and hitching the horses between the wheels, was considered in the chapter on Earth Roads—see § 187–93.

365. Effect of Wheels. There are three effects of the passage of a wheel over a broken-stone road: (1) the grinding and crushing action; (2) the effect of the load in giving rise to bending and cross-breaking stresses throughout the whole thickness of the road covering; and (3), when the road metal is loose and not bound together, a displacement of the stones among themselves. If the road is properly rolled and a good binding material is used, there will be no movement of the stones among themselves, with a consequent wear and waste of materials; and if the road has a thickness proportionate to the load and to the supporting power of the foundation, there will be no cross bending. Consequently with a reasonably well constructed road, the only effect of the wheel is its grinding and crushing action.

This effect of the wheel varies greatly with the condition and material of the roadway. If the surface is perfectly smooth and the load per unit of area is not beyond the crushing resistance of the stone, the amount of wear is probably insignificant, and possibly is beneficial to a certain extent, since a certain amount of dust is necessary to replace that inevitably swept away by wind and water; but the moment irregularities of any kind occur on the surface, deterioration begins, since the wheels then immediately begin to pound. When the pressure of the tire is greater than either the crushing strength of the stone or the cohesive strength of the binder, the damage is very great.

366. Horses' Feet. It is conceded that the picking of the horses' feet is one of the most serious causes of damage to a broken-

stone road. The impact of the shoes tends to displace the exposed stones and to loosen the binding material; and the dislodgement of one fragment makes it easier to displace others. The surface irregularities produced in this way are continually increased by the impact of the wheels, and the binding material thus loosened is more readily carried away by wind and water. The breaking of the binding material also permits water to penetrate more easily into the road-bed. The effect of the horses' feet is particularly destructive on a steep grade—both in ascending and in descending.

367. Tracking. The tendency of a team to follow the track of the preceding vehicle leads to the formation of ruts. If drivers would vary their track only a few inches, one set of wheels would counteract the effect of the others, and the road would remain comparatively uninjured. The advantage of this is proved by the fact that wherever there is a turn in the road the ruts disappear, however deep they may be on the straight part, because the horses naturally vary their course round the corner, and one wheel obliterates the track of the preceding one. Tracking is easily remedied by a little attention on the part of the driver; and to secure this, sign-boards calling the driver's attention to the disadvantage of tracking, are sometimes set up Legible signs at each half mile and at prominent points have proven very effective in preventing tracking and the consequent ruts. Sometimes piles of stone or barricades are placed upon the road to direct travel temporarily. The barriers are sometimes so arranged as to keep the travel in parallel straight lines, and sometimes so as to force the traffic to move in gentle serpentines. The barriers are changed from time to time so as to distribute the travel over every part of the road. This method of limiting the travel is applicable only on comparatively wide roads; and even then it is not defensible, owing to the obstruction of traffic.

368. Wind. The strong winds which prevail over a large part of this continent, in connection with long droughts, remove the dust from between the fragments of the stone. This effect is more serious on the less frequented highways, since the sparse traffic does not make enough dust to renew the cement in the crevices between the stones, particularly as some of it is also liable to be washed away by rains.

369. Rain. The action of violent rains in destroying broken-stone roads is an important factor, and somewhat peculiar to this country. The rain often removes the binding dust between the top stones to such a degree that they become loosened. This effect is specially important on slopes of considerable declivity, as is shown by the "raveling out" which often occurs on steep grades or on roads which have an excessive crown. This indicates that on grades the crown should be only sufficient to turn the rain water speedily into the side ditches.

A moderate amount of water, if gently applied, is an advantage to a broken-stone road, since the cementing action of the binding material is greater when wet, and for this reason sprinkling is an important factor in maintenance (§ 380).

370. Frost. Although freezing and thawing has little or no effect upon the individual pieces of stone (§ 737), frost has a very injurious effect upon the road as a whole. It is desirable that the binding material shall at all times be wet, and if the construction is defective or the maintenance poor, there is a liability of considerable water being present in the road-bed; and this water in freezing expands, breaks the bonds, and makes the road open and porous. A road that has been well filled and thoroughly rolled will have only a small per cent of voids, and therefore there will be but little water retained in the body of the road and consequently be but little damage from frost.

371. Decomposition of Stone. It is sometimes claimed that chemical decomposition of the stone is a cause of deterioration of a broken-stone road; but this effect is so small as to be entirely inappreciable. On the contrary, the decomposition of the stone may be an advantage to such a road. Many of the rocks employed in road building are slightly soluble in water containing carbonic, nitric, or sulphuric acid gathered from the atmosphere, or in water containing humic acid derived from the decomposition of vegetable and animal matter; and consequently any rain or surface water which penetrates a broken-stone road may dissolve the fine stone dust and afterwards deposit it in the interstices lower down, where it will act as a cementing material. This may be, at least in part, the explanation of the well known fact that a crushed-stone road, for a time at least, improves with age. The improvement

is doubtless also in part due to the gradual infiltration into the smaller interstices of the binding material of very fine particles of dirt from the surface.

372. AMOUNT OF WEAR. The amount of wear will vary greatly with the climate, the amount and character of the traffic, the nature of the stone, and the method of construction.

It has been estimated * that in Great Britain 20 per cent of the wear was due to atmospheric causes and 80 per cent to the traffic and that with fast stage coaches three fourths of the wear by traffic was due to horses' feet and one fourth to the wheels, while with ordinary vehicular traffic about six tenths was due to the horses' feet and four tenths to the wheels. The relative wear from horses' feet and wagon wheels was deduced from a comparison of the wear of iron in the horses' shoes and in the tires of the wheels; but it is not stated upon what the estimates of the wear from atmospheric causes were based. Any such general estimate must not be considered as even approximately true for any particular case, since the relative wear varies greatly with the exposure to sun and wind, the drainage, the strength of the road, the character of the maintenance, etc.

In France, where the relation between the wear and the traffic has been carefully studied, some engineers maintain that the wear increases in the same proportion as the traffic, while others contend that the wear increases in a greater ratio than the traffic. Table 25, page 246, is frequently cited to establish the latter view. These data were obtained in the following manner: Owing to the falling in of a tunnel, the traffic on a particular road was suddenly increased from its usual amount of 1,378 tons per day to 2,264 tons, 3,150 tons, and 5,315 tons on different sections, at which rates it continued for 74 days, after which it fell on all portions of the road to 1,772 tons per day. The consumption of material was determined by measuring the amount of detritus removed from the road and also by comparing the amount of material less than 2 centimeters in diameter in the body of the road at the beginning and the end of the period. According to Table 25, increasing the

* By Sir J. Macneill before a Parliamentary Committee in 1831,—see Codrington's Maintenance of Macadamized Roads, p. 69.

TABLE 25.

RELATION OF TRAFFIC AND WEAR.*

Daily Traffic.	Annual Consumption of Materials per Mile.	Annual Consumption per Mile per 100 Tons of Daily Traffic.
1 378 tons.	724 cu. yd.	52 cu. yd.
1 772 "	1 857 " "	104 " "
2 264 "	2 780 " "	122 " "
3 150 "	4 615 " "	146 " "
5 315 "	9 886 " "	186 " "

traffic four-fold increased the wear thirteen-fold; but the case was an extreme one, since the increased traffic was unusually heavy, and since the road material, schist, is unusually friable and deficient in cementing power. Under the 1,378 tons per day, the wear was at the rate of 1¾ inches per annum; and under the 5,315 tons per day, it was at the rate of more than 2 feet a year. Apparently a majority of road engineers hold that an increase of traffic increases the wear per ton, but in a much less ratio than in Table 25. It is certainly true that heavy loads cause more wear than light ones, even when the total weight transported is the same.

373. In France careful observations are made by the government engineers to determine the amount of wear in terms of the traffic. The traffic is expressed in "units" representing a horse harnessed to a loaded wagon; and to reduce the other traffic to this unit, the following values are used:

1. Each horse hauling a public vehicle or a cart loaded with produce or merchandise 1
2. Each horse hauling an empty cart or a private carriage .... ½
3. Each horse, cow, or ox unharnessed, and each saddle-horse .... ⅓
4. Each small animal (sheep or goat) 1/20

In 1876 the average amount of material required for the Routes Nationales was 53 cubic yards per mile per 100 "units" of daily traffic, the range for the different departments being 15 to 265, but usually from 27 to 102.† In 1893 the average was 49 cubic yards per mile per 100 "units" of travel, the stone having an average co-efficient of wear (§ 282) of 10.85.‡

* M. Graeff in *Annuales des Ponts et Chaussées*, Vol. 9, 1865—as quoted by Codrington in Maintenance of Macadamized Roads, p. 89.

† Codrington's Maintenance of Macadamized Roads, p. 91.

‡ Rockwell's Roads and Pavements of France, p. 67.

374. In Austria the traffic has not decreased, but the material employed in repairs has continually decreased since 1856. From 1865 to 1872 the average consumption of material was 84.9 cubic yards per mile per annum per 100 vehicles.

No observations seem to have been made to determine the relation between wear and traffic for English or American roads.

Professor Shaler says: "If the wear on macadam is more than $\frac{3}{4}$ inch per year the presumption is that true economy demands a more enduring form of pavement." *

375. METHODS OF MAINTENANCE. There are two general methods of maintenance, which may be called (1) continuous maintenance and (2) periodic repairs. By the first system the waste on account of traffic is supplied gradually as it is worn off by adding a patch here and there, and so the full thickness of the road is constantly maintained; while by the second system the road is permitted to wear thin, and then an entirely new surface is added, although this system does not exclude small repairs, but limits them to the timely filling of holes and ruts to check more extensive damage to the road. The system of constant maintenance is the one generally employed in Europe; while in America periodic repairs seems to be the more common, although both systems have their ardent advocates.

Those favoring continuous maintenance claim (1) that it is the only system that gives a constantly good road, since with periodic repairs the road is seldom good, being bad just after repairs, becoming passable after a time, and then deteriorating until repaired again; and (2) that continuous maintenance is the cheapest in the long run. Those favoring the periodic system of repairs claim (1) that a well built road will wear uniformly until so thin as to need re-surfacing; (2) that the system of continuous maintenance does not give as good a surface as the other method, since the new material is constantly being added at every point to supply the loss of wear, and this material must be consolidated by the traffic; and (3) that the system of maintenance by patching is excessively expensive, requiring a needless amount of material and labor.

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* American Highways, p. 224.

There seems to be an irreconcilable conflict between the theories of the two sides; but in practice, under similar conditions, there is not as great a difference as a statement of the theories seems to indicate, the difference in opinion being largely due to a difference in the conditions assumed. In France, where the maintenance of broken-stone roads has been the subject of prolonged and careful observation by the officers of the Corps of Roads and Bridges, the system of continuous maintenance is employed on roads of moderate traffic, i. e., roads 18 to 20 feet wide having a traffic not exceeding about 600 tons per day; and the system of periodic repairs is employed upon roads of great traffic, i. e., roads 18 to 20 feet wide having more than 600 tons per day. These limits would doubtless vary with the nature of the road material, the method of construction, the climatic conditions, the character of the traffic, etc. It is claimed that the system of periodic repairs "is growing in favor in France, and in 1893 more than half the stone employed in making repairs was applied under this system. The method is used exclusively in general repairs of the macadamized streets of Paris." *

376. Work of Maintenance. Under this head will be discussed the several kinds of work involved in taking care of a crushed-stone road and in making repairs.

377. Raveling. One of the chief evils to be contended with in the maintenance of a crushed-stone road is the tendency to ravel, i. e., for one stone after another to work loose on the surface. This occurs only after a long dry spell or in a road originally deficient in binding power, and is more likely to occur on lightly traveled roads than on those having heavy traffic. Raveling may take place where the wind sweeps away the binding material from the surface, or on a steep grade where the water has washed the fine material away from between the fragments; and is chiefly due to the picking of the horses' shoes, and is in a measure counteracted by the rolling action of the wheels.

At least three expedients are employed to prevent raveling. 1. Sprinkling the road with water effectually stops raveling, and causes the surface to solidify again. This is the most common

* Rockwell's Roads and Pavements of France, p. 43. Wiley, New York, 1896.

remedy on city streets and suburban roads—where water is usually convenient and plentiful. For a further discussion of Sprinkling, see § 380. 2. A thin coating of coarse sand is very effective in preventing raveling. Ordinarily on country roads a layer half an inch thick over the middle 8 feet of the trackway is sufficient. Unless the season is very dry or the road is unusually exposed to the wind, a single application will be enough for one season; but in extreme cases two or even three applications may be necessary. It is important that the sand be reasonably clean and coarse, as otherwise it will be blown off by the wind or be washed away by occasional showers. If the sand is accompanied by iron oxide, all the better, as it adds to the cementing power and aids in preserving an impervious covering, which tends to prevent evaporation of the moisture below the surface. The coating should not be very thick, or it will yield under the wheel and interfere with travel, besides being unsightly. The usual tendency is to add too much sand, or to substitute loam or clay for part or all of the sand. Clean coarse sand gives the best results. 3. The third method of preventing raveling consists in incorporating blue gravel or a small amount of hard pan or clay with the stone screenings used for surfacing the road during construction. The blue gravel and clay are high in cementing power, and when mixed with screenings make a hard and elastic surface which stands both wet and dry weather reasonably well, and does not allow the surface to ravel.

378. Ruts. Next after raveling, the tendency to form ruts is the most serious evil to be contended against in the maintenance of crushed-stone roads. Ruts are due either (1) to a greater wheel load than the road is capable of standing, or (2) to the use of an inferior binding material, as loam, or (3) to tracking (§ 367). Ruts are most likely to occur in the spring or during a wet time, when the road-bed is soft, and are more common on country roads than on city streets, since in the latter the frequent changes in direction to avoid other vehicles produce a more uniform wear over the whole surface of the road. A street-car track in a broken-stone road prevents the distribution of traffic uniformly over the entire surface, and greatly increases the tendency to form ruts.

After ruts appear the only remedy is to fill them either with new material or by picking down the sides of the ruts and raking

the loosened material into the depression. Usually the latter course is the wiser, particularly on a new road. Frequently the tendency to form a rut may be effectually arrested by sweeping into it the loose detritus from the adjacent parts of the road. If the road surface is compact and hard, it may be necessary to loosen the bottom and sides of the rut before adding new material, so that the new will thoroughly unite with the old. The new material should be of the same character as the old, as otherwise the surface will wear unequally and become rough. For additional suggestions applying to this subject, see § 385.

379. Rolling. In the spring after the frost goes out, the road-bed is soft and porous; and a thorough rolling with a steam roller at this time, before the subgrade is dry, is one of the best and cheapest methods of keeping a stone road in good condition. Just before this rolling is the time to add a little fresh surface material, here and there, as may be needed to fill up slight depressions. For precautions to be taken in filling these depressions, see § 385.

380. Sprinkling. While water in excess is an enemy of crushed-stone roads, moisture in a moderate quantity is a great benefit. Moisture is necessary to preserve the cementing power of the binding material, and also to prevent an excessive removal of dust by the wind; and therefore sprinkling to the measure required to prevent these injuries is an advantage. The water should be applied in a fine spray, and not be allowed to run in streams on the road; that is, several light sprinklings are better than a single flooding. If sprinkled too heavily or too often, the road is softened and breaks up easily.

Sprinkling is usually employed on park drives and city streets, where it is generally conceded to be true economy, without taking into consideration the prevention of dust; but on account of the expense, it is likely to be many years before this refinement is adopted for rural roads. The cost of sprinkling will vary greatly with the cost of water and the length of haul. It has been estimated that the annual expense of sprinkling country roads would be $75.00 per mile.*

381. In some localities, particularly in California and at the

* Shaler's American Highways, p. 162.

seaside summer resorts in New Jersey, broken-stone roads have been sprinkled with crude petroleum to prevent dust. The oil is applied hot, with a sprinkler, when the road is dry, and only in such quantities as will be readily absorbed. An elastic cushion is thus produced, which is practically impervious to water, and which holds the dust and screenings from blowing and washing from the surface and reduces the wear due to travel. From 50 to 60 barrels per mile are required for the first treatment, and about 20 for each subsequent application. Two or three applications are made per year.

382. Removal of Mud. Considerable material must be removed from the road surface. Traffic grinds the road metal into dust, mud is brought in from the unpaved side-roads, and the horses drop a large amount of dung. All superfluous dust should be removed for the comfort of both travelers and adjacent property owners. However, to prevent the surface stones from working loose, it is customary to keep the surface of the road damp by sprinkling, and therefore the detritus to be removed is chiefly in the form of mud. The removal of the mud prevents the formation of tracks, and therefore greatly decreases the tendency to produce ruts. An accumulation of mud retains water, which softens the road and increases the wear.

The more sticky mud is removed with a shovel or a special mud scraper; and the more fluid mass is removed with brooms. A laborer by hand can ordinarily clean 700 to 1,000 square yards per day. The sweeping should not be so thorough as to remove the binding material from between the surface stones.

Mud-scraping machines are upon the market which consist of a series of narrow spring scrapers, and which will clean 5,000 to 6,000 square yards per hour at a less cost than can be done by very cheap hand labor. It is necessary to use them with great care, to avoid loosening the surface stones. Machine brooms are usually employed for this work where the road is cleaned at frequent intervals. The ordinary form consists of a cylindrical brush or broom about 16 inches in diameter and 7 feet long, attached beneath the axle and connected by suitable gearing with the wheels of a vehicle drawn by one or two horses. The axis of the broom is set horizontally at an angle of about 40 degrees with the axle of the

vehicle. When working, the broom rests firmly on the surface of the pavement or road-covering and revolves in a direction opposite to that of the wheels, sweeping the dust sidewise from a strip about 5½ feet wide and leaving it in a ridge behind the rear end of the broom. In using this machine upon a broken-stone road, the precaution should be taken to see that the brush is not too stiff. What would be entirely suitable and in all respects well adapted for sweeping pavements of stone blocks, wood, or asphalt, might injure the surface of a broken-stone road by penetrating too deeply, thereby loosening the stones at the surface and destroying the bond. The detritus is deposited on the side of the road, and subsequently removed in carts or wagons.

383. The mud is usually removed from broken-stone roads in the cities, but not from rural highways. In those localities where the soil is sticky, as for example in the prairie regions of Illinois and Iowa, keeping the crushed stone free from mud is a serious problem, particularly if most of the side roads are unpaved. Further, certain somewhat unscientific attempts at road building in such localities seem to show that serious difficulties may be encountered by the road surface's being picked to pieces by the adhesion of the mud. It is a serious question whether broken-stone roads can be built in such localities with sufficient binding power to resist the adhesive action of the mud.

384. Drainage. At any season of the year anything that impedes the free discharge of the rain water from the surface should receive careful attention. Water lodging in a depression should not be drained off by a trench to the side of the roadway, but the hole should be filled up (§ 378); and the gutters should be kept free from mud and rubbish. In the fall, all weeds and grass in the ditches should be cut and removed, and the culverts and outlets should be left free and open. All ditches and culverts should be inspected in advance of the spring rains; and in northern localities where snow lies for considerable time, the outlets of all water courses should be opened before the spring thaw sets in.

385. Patching. If the road is maintained in good repair, there will be no deep holes or ruts, but only shallow depressions or slack places which show where fresh material should be applied. These depressions are deepest at the center and gradually grow shallower

toward the edges. Care is required in determining the size and shape of the patches of stone to be spread in these hollows. Inexperienced workmen are inclined to lay stones in rectangular patches, with more regard to the neat appearance of the newly spread stone than to the needs of the road, and thus parts of round or oval-shaped hollows are left uncovered, or stone is spread where it is not required. The angles of a square patch are very liable to be knocked away; and even if the stones are not wasted in this way, they do not set as quickly as if laid in a round form. If the ends of a patch be made in the form of an oval, more or less pointed, the traffic will gradually work over it from the sides; and on a hill the water will be diverted towards the sides of the road instead of running into the stone, as it does with a square-ended patch. Care should be taken to cover the whole surface of the depression so as to leave no place where water may lodge; and the depression should be filled full enough so that after consolidation of the surface, the patch will conform to the original cross section of the road. If the hole is not filled full enough, it will soon appear again in the same place; and if it is filled too full, other depressions will form on each side of the patch.

If from neglect or bad management, long ruts or large hollows have been allowed to form, they should be repaired in short lengths and one part at a time. Horses avoid long strips of stones laid in a hollow worn by wheels, and soon make another rut alongside. Laying a long strip of materials on the middle of the road diverts the traffic to the sides, which are sure to suffer a good deal and may be entirely cut up before the stones in the middle are compacted. To avoid retarding the travel and increasing the draft too much, a new coat should not be put on any continuous space larger than 5 or 6 square yards. If several depressions are found very near each other, fill the worst and attend to the next after the first has become solid.

The stone employed in patching should be a little smaller than that of which the road was originally constructed; and should never be applied in a thick coat. A layer one-stone thick after consolidation is enough; and if the stones are sufficiently close to support each other, such a course will bond well. If one such coat is not enough, a second may be added when the first is nearly consolidated.

Ordinarily, in applying patches in thin coats over small areas it is unnecessary to use binding material, since the road usually has enough detritus to fill the interstices of the new stone. If laid in damp weather, when the surface of the road is soft, there is usually no difficulty in getting a layer one stone thick to consolidate without any binding material. If the surface is very compact, or if the new stone is very hard, it may be wise to loosen the old surface around the edge of the patch with a pick, and also to scrape the detritus from the surface of the road and apply it to the edge of the patch. In extreme cases, it may be necessary to add a binding material. Screenings, or sand with considerable clay will greatly facilitate binding; and after the traffic has forced the surplus clay to the surface, it can be scraped off. Such a patch will finally become firm and hard.

If the patch is small and thin, it will usually be thoroughly consolidated by the traffic; but if it is thick, it may be necessary to tamp it. However, as a rule, it is much better to lay successively two thin courses than one thick one.

386. The method of continuous maintenance is a method of constant patching. This method contemplates restoring to the whole length of the road an amount of stone equal to the annual loss by wear, and therefore it is necessary to do more than just fill the holes and depressions as described in the preceding section.

In maintaining the road by patching, it is impracticable to employ a roller, and therefore the patches must be put on in such a manner as to induce travel to consolidate the new stone. The method of accomplishing this is as follows: The first patches are made along the middle of the road at intervals of about 50 yards, without reference to any depressions that there may be between. These patches have the shape of elongated rectangles, about 3×8 feet. The whole section having been gone over in this way, the roadman commences again at the original starting-point and makes new patches, checker-board fashion, alternately on the right and the left of the first patches and midway in the space between them. On the third trip, he makes new patches between the second set; and so on, always observing the checker-board arrangement. Thus in five trips the whole central part of the roadway has been covered, while travel has been induced to

change direction five times and virtually to pass over nearly the whole surface.

387. Re-surfacing. The term re-surfacing is frequently applied to two distinct operations. One consists in smoothing and leveling up the surface of an old road without adding much, if any, new material; and the other consists in adding an entirely new layer of material to an old road. For greater clearness, the first will here be called re-grading, and the second re-coating.

388. Re-grading. When the surface of the road has become uneven and rough, and when the broken stone is thick enough not to require much new material, the top of the road is loosened, re-graded, and re-rolled. The loosening is usually done by running over the road, one or more times, with a steam stone-road roller having spikes in the rear wheels—see Fig. 66. Of course

FIG. 66.—STEAM ROLLER SPIKING OLD BROKEN-STONE ROAD.

the roller must be heavy enough to force the spikes into the road metal; but to insure this condition the size of the spikes is usually thus adjusted to the weight of the roller. The amount of rolling required depends upon the hardness of the road and the amount of hand labor used; in one case a 12-ton roller loosened 240

square yards of a hard limestone per hour.* The spikes break up the layer to a depth of 3 or 4 inches, after which men complete the loosening process by breaking up the larger masses with hand picks. Sometimes the old road is broken up by a plow drawn by a steam roller; but ordinarily this is not as good as using the spikes on the roller, since the road is not broken up to a uniform depth, and since there is danger of mixing the under-material with the top course, thus rendering the latter unfit for use again. Sometimes a harrow follows the plow or the roller.

After the crust is broken up, the surface is leveled off by the use of shovels and rakes; and then it is sprinkled and rolled as in the original construction. Usually no new binding material is required, the detritus from the old road being sufficient.

The following tabular statement shows the distribution of the labor and the cost of re-grading a limestone road having an exceedingly hard crust:*

Loosening with roller @ $1.00 per hour	0.4 cents per sq. yd.
Picking by hand @ 20 cents per hour	1.2 " " " "
Re-spreading @ 20 cents per hour	0.8 " " " "
Rolling @ $1.00 per hour	0.33 " " " "
Sprinkling with cart @ 40 cents per hour	0.13 " " " "
Foreman—143 hours for 9,400 sq. yds. @ 30 cents per hour	0.44 " " " "
Total cost of re-grading	3.30 " " " "

Re-grading is applicable only when the road wears unexpectedly rough and uneven, or when the road was originally made needlessly thick. It is not economical to spend time and money in consolidating a thick layer part of which must later be loosened and re-consolidated. True economy requires the construction of a road of such a thickness that when the surface is too rough and uneven for further service, the road will be worn so thin as to require a layer of new material—which should be added without materially disturbing the old surface; that is, it is more economical to construct a thin road and give it a new top as occasion may require, than it is to build a thick road and re-grade it one or more times before it is worn so thin as to require a new top layer.

389. Re-coating. All dust or mud should be removed from the

* *Engineering News*, Vol. 45, p. 411.

old surface before adding the new material. Where the surface of the old road is very compact and the new material is hard and tough, it may be necessary to loosen the surface with picks to the depth of ½ an inch, to secure a good bond between the old surface and the new material; but usually it is sufficient to score the surface with a hand pick, making gashes 8 to 12 inches apart, having a maximum depth of ¾ of an inch. If the sides of the road need no new material, a shallow groove having its outer face vertical should be cut longitudinally along the edge of the portion to be covered, so as to form a buttress for the new top and to secure a good union of the old and the new material. Where water is plentiful, it is wise to soften the surface by copious sprinkling, to insure a firm bond between the new material and the old road-bed. The new stone is to be spread, rolled, and sprinkled just as in new construction.

The cost of labor to lay 21,908 square yards of a 3-inch course of 2-inch trap rock, bound with trap screenings, in New York City in 1897 was as follows: *

Scraping and sweeping	2.00	cents per sq. yd.
Picking old surface	1.50	" " " "
Spreading stone	2.00	" " " "
Rolling (47.15 sq. yd. per hour)	2.76	" " " "
Total cost of labor in re-coating	8.26	" " " "

390. Cost of Maintenance. The cost of maintenance varies greatly with the quality and cost of the stone used, the amount of travel per unit of width, the climatic conditions, the cost of labor, the length of time considered, and the state in which the road is maintained; and consequently any general data are liable to be misleading when applied to a particular case.

There are almost no valuable data concerning the cost of maintaining American broken-stone roads. The Reports of the Massachusetts Highway Commission for 1900 and for 1901 give definite information concerning the expenditures for repairs on state-aid road; but these data, although frequently quoted, are without general significance, since all of the roads are comparatively new, being from 1 to 5 years old, and the expense for the

* Trans. Amer. Soc. of Civil Engineers, Vol. 41, p. 127.

different ages is not separated, and since the roads are in widely separated sections varying from ½ to 5 miles in length, and further since a considerable part of the expenditure for maintenance was for the purchase of sufficient repair stone to last for several years. "The cost of maintenance, which was about equally distributed over the roadway and the roadside, consisted of cutting brush and weeds, cleaning waterways and gutters to permit a free flow of water, trimming down the shoulders, cutting small waterways through them, and filling washouts." The roads are maintained by the continuous repair system; and as soon as the length of any one section will justify, the road is to be put under the care of a man constantly in attendance.*

Michigan Boulevard, Chicago, a 50-foot granite macadam driveway from which heavy traffic teams are excluded but which has a very large travel, costs for maintenance per annum as follows: †

Sprinkling	4.9	cents per sq. yd.
Sweeping and removing manure	7.8	" " " "
Patching here and there	0.6	" " " "
Re-coating surface	15.0	" " " "
Total annual cost of maintenance	28.3	" " " "

This is a city street under the control of the South Park Commissioners, and is continuously maintained in a first-class condition.

Driveways in the South Side Parks, Chicago, 40 feet wide, with a crushed limestone surface, cost as follows per year for maintenance: †

Sprinkling	4.8	cents per sq. yd.
Sweeping and removing manure	3.0	" " " "
Patching here and there	0.5	" " " "
Re-coating surface	1.7	" " " "
Total annual cost of maintenance	10.0	" " " "

In the Boston Parks, the annual cost of repairs of a telford crushed-stone road was $189.00 per mile, of which $129.00 was for stone screenings, $49.00 for teaming, and $20.00 for labor. The sprinkling cost $721.00 per mile, of which the water cost $187.00 (16 cents per 1,000 gallons), and the teaming $533.00.‡

* Report of Massachusetts Highway Commission for 1901, p. 22-23.

† J. F. Foster, Superintendent and Engineer of South Park Commissioners.

‡ Jour. Association of Engineering Societies, Vol. 10, p. 235.

391. In France, elaborate and carefully analyzed accounts are kept of the cost of maintaining the public highways; but owing to differences in the climatic conditions and the prices of labor, and also owing to variations in the character of the road metal, such data are valuable only for the particular locality.

There are 321,803 miles of stone roads in France, which is equivalent to 1 mile of road for each 0.66 square mile of area or 1.52 miles of road per square mile, and to 1 mile of road for each 119 inhabitants. The average cost of maintenance per mile is about $223.00 per square mile of area, and about $1.39 per inhabitant. Table 26, gives a summary of the annual expenditures for material and labor for the roadway proper. To obtain the total cost of maintenance, add about 45 per cent to the results in Table 22 to cover expenditures for water courses, sidewalks, planting of trees, and general administration.

TABLE 26.

OUTLAY FOR MATERIALS AND LABOR ON THE ROADWAY PROPER IN FRANCE.*

Ref. No.	Class of Road.	Length, Miles.	Annual Cost of Maintenance.	
			Total.	Per Mile.
1	National roads..........	22 009	$4 333 500†	$225.00
2	County roads	16 188	2 794 723‡	172
3	Township roads	128 522	15 835 100‡	123
4	Neighborhood roads	155 093	8 488 537‡	55
	Total	321 093	31 551 860	$98.05

* Rockwell's Roads and Pavements in France, p. 67.
† For 1893. ‡ Average for three years, 1886–88.

The following are some of the details of the cost of maintaining the National Roads of France during 1893:

Number of miles..........	22 009
Average travel in 24 hours, "units" (see § 373)..........	170.6
" amount of broken stone required (including 7½ per cent of binding gravel) per mile per 100 "units," cubic yards......	49.
" quality of stone, i.e., average coefficient of wear (§ 282)....	10.85
" cost of stone, per cubic yard..........	$1.17
" " " binding gravel, per cubic yard..........	$0.36
" labor cost per mile per 100 "units"..........	$30.71
" " " " cubic yard of material used..........	$0.63
" wages of roadman per day..........	$0.55
" cost per mile per 100 "units" for materials..........	$58.75
" " " " " 100 " " labor..........	$30.71
Total average cost per mile per 100 "units" for material and labor	$89.46

In the Department of Havre, France, the average annual cost of sweeping, removing mud, watering, and maintaining all works is as follows: for departmental roads in the cities 3.0 cents per square yard, and in the country 1.8 cents, and for communal roads 1.1 cents per square yard.*

392. Economics of the Stone Road. For a few remarks on the advantage of a permanently hard road surface, see § 265, which statements concerning gravel roads apply with equal force to stone roads.

There is a certain financial advantage in a crushed-stone road, but whether its construction will be true economy is a problem that can be solved, even approximately, only for each individual case. The solution of the problem requires the correct determination of the following items: the cost of construction of the new road, the cost of maintenance for the old road and also for the new, the cost of transportation on the old and the new road, the amount of traffic both before and after the improvement, and the rate of interest. To illustrate the method of using such data, an example will be assumed.

It is assumed (1) that the cost of construction is $5,000.00 per mile; (2) that the annual interest is 5 per cent; (3) that the annual traffic is 5,000 tons in full loads; (4) that the average cost of maintenance of the present earth road is $40.00 per annum; (5) that the annual cost of maintaining the proposed stone road is $200.00 per annum; (6) that the cost of transportation in full loads on the present earth road is 15 cents per ton mile; (7) that the cost of transportation on the proposed stone road is 5 cents per ton mile. The account would then stand about as follows: The annual cost of a mile of the stone road is equal to the interest on $5,000 at 5 per cent or $250 *plus* the difference in cost of maintenance ($200 − $40) = $160; and the total cost is $250 + $160 = $410. The annual saving by the stone road is 10 cents per ton mile on 5,000 tons, or $500 per annum. This example shows a saving of $90 (= $500 − $410) per annum per mile by the construction of the stone road. In connection with the above computation the following limiting conditions should be remembered:

* Special U. S. Consular Reports on Streets and Highways in Foreign Countries, p. 71.

1. The cost of the stone surface will depend upon the locality, the width of the road, and the character of the construction. Considerable expense may be required to reduce the grades; for unless the grades of stone roads are light, the cost of transportation is not much less than that on an earth road. The cost of construction should include the cost of building new bridges or of strengthening old ones, to permit the passage of the heavier loads incident to the economic use of the stone road.

2. Five per cent interest is too small for some localities, but is too great for many communities; and it may reasonably be assumed that in the future interest rates will gradually decrease. The lower the interest the better the opportunity to secure improved roads. If the road is to be financially profitable, the original cost must be considered a business investment which will pay dividends.

3. In considering the financial value of the proposed improvement, only full loads should be included in computing the saving in cost of transportation; but in any probable case there will also be a miscellaneous traffic which will be benefited by the better road. The benefit to any but full loads will be chiefly in the saving of time; but the value of this saving can not be computed, since it will depend upon the value of small fractions of time for other purposes.

4. The cost of maintenance of the present earth road and also of the proposed stone one should include the periodic repairs or renewals of bridges and culverts.

5. The cost of maintenance of the stone road should include not only the cost of petty repairs during the first few years of the life of the road, but also the cost of periodically renewing the surface. The cost of maintenance will vary with the climatic conditions, the nature of the soil, the character of the road material, the amount of traffic, the price of labor, etc.

6. The cost of transportation on either the earth or the stone road depends upon whether it is done by a freighter or a farmer (see § 4–7), and also upon the climate, the nature of the soil, the grades, etc.

7. If the hauling is done upon wagons used chiefly in general farm work or upon earth roads, the capacity of the wagon will limit

the load, and hence the full economic advantage of the hard road surface can not be secured.

Further, there is some financial advantage in being able to use the roads at any season of the year, but such an advantage can not be computed for a general case nor usually in a particular case. Finally, there is a social advantage in permanently good roads (see § 1) that should not be overlooked in considering any proposed road improvement.

CHAPTER VI.

MISCELLANEOUS ROADS.

393. Wheelways. When wheeled vehicles are drawn by horses, the wheels should move on the smoothest and hardest surface possible, while the horses require a surface rough enough to give them a secure foothold and soft enough to be easy to their feet. The two opposite requirements are united only in wheelways, i. e., in roads in which two parallel rails of suitable material are provided to receive the wheels, while the space between the rails is filled with a different material, on which the horses travel. In ancient times, stone wheelways were of considerable importance; and because of this, and of the frequent proposals now-a-days to build wheelways of steel and burned clay, this class of roadways will be briefly considered.

394. Stone Wheelways. The Egyptians seem first to have discovered the value of stone wheelways. In modern times they have been used in London and other European cities, but apparently have been abandoned save in northern Italy.

Telford made an ingenious use of wheelways on his Holyhead road (third paragraph of § 304). Two hills, each a mile in length, had an inclination of 1 in 20. To reduce the grades to 1 in 24 would have cost $100,000. Nearly the same advantage in diminishing the tractive force was obtained by moderate cutting and embanking and by making stone wheelways, at a total expense of less than half the amount the grading would have cost. The construction was as follows: "The blocks were of granite, 12 inches deep, 14 inches wide, and not less than 4 leet long. A foundation for them was prepared by making an excavation 8 feet wide and 25 inches deep. On its leveled bottom was laid a telford pavement (§ 302) 8 inches deep, the interstices being filled with gravel.

Upon this pavement were laid 3 inches of broken stones, none exceeding 1½ inches in their longest dimensions. On these stones was a layer of 2 inches of the best gravel, over which a heavy roller was passed. Upon this the stone blocks or trams were laid to a very accurate level. On each side of the blocks was placed a row of paving-stones of granite, 6 inches deep, 5 inches wide, and 9 inches long. The remaining space between and outside of the lines of paving stones was filled up with hard broken stone, and the whole was covered with a top dressing of one inch of good gravel."

395. Steel Wheelways. In recent years there have been many proposals to build steel wheelways. Numerous designs have been offered for the rail, most of which are highly impracticable, being difficult to manufacture, to lay, and to maintain. A number of the rails would require the construction of expensive machinery for their manufacture before they could be tried even experimentally. Three or four sections from 16 to 180 feet long have been built, and for a time were exploited in the newspapers; but even a little experience with them showed that they were practically worthless. A short section well cared for on dry ground under an experimental wagon gives little or no indication of the result under the ordinary conditions of actual service.

Apparently the first steel wheelway was constructed in Spain in 1892 from Valencia to Grao—a distance of two miles. Valencia has a population of about 170,000 and Grao is the seaport. The road is a double track, and the space between the rails and adjacent to them is paved with stone blocks. The rail consists of two inverted trough sections bolted together,* and apparently simply embedded in the sand. The cost, including the paving, was $7,665 per mile of single track. The traffic is said to be 3,200 vehicles a day. The cost of maintaining the former macadam surface was $5,470 per annum; and since the opening of the steel wheelway, the cost of maintenance is said to be but $380 a year. For several reasons, this example is not a very valuable guide for American practice.

396. The only practical test of a steel wheelway ever made in this country was upon a section built in Chicago in 1901 from

* For detailed illustration, see *Engineering News*, Vol. 42, p. 367.

designs prepared in the Office of Road Inquiry of the U. S. Agricultural Department. Fig. 67 shows the cross section proposed

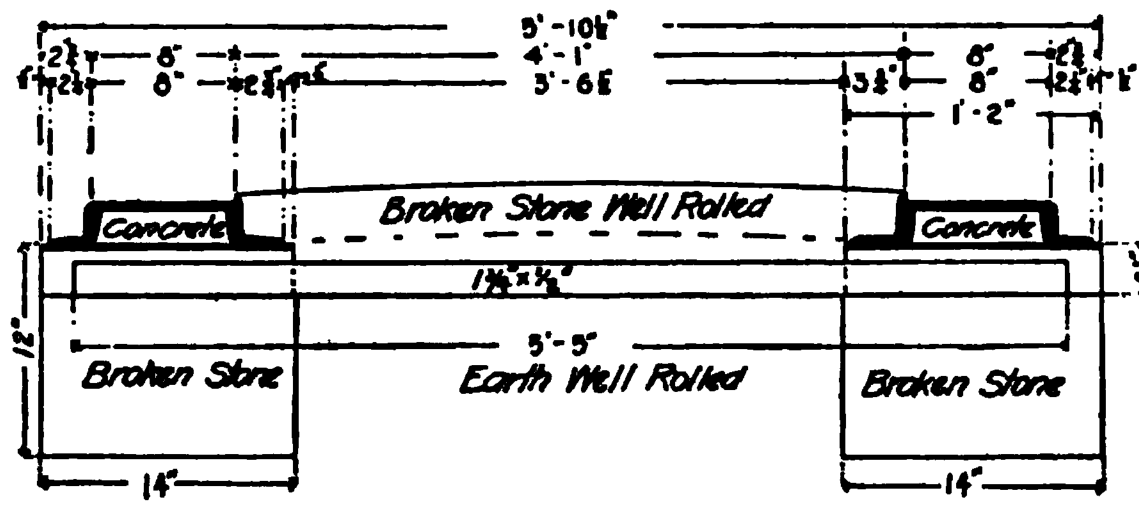
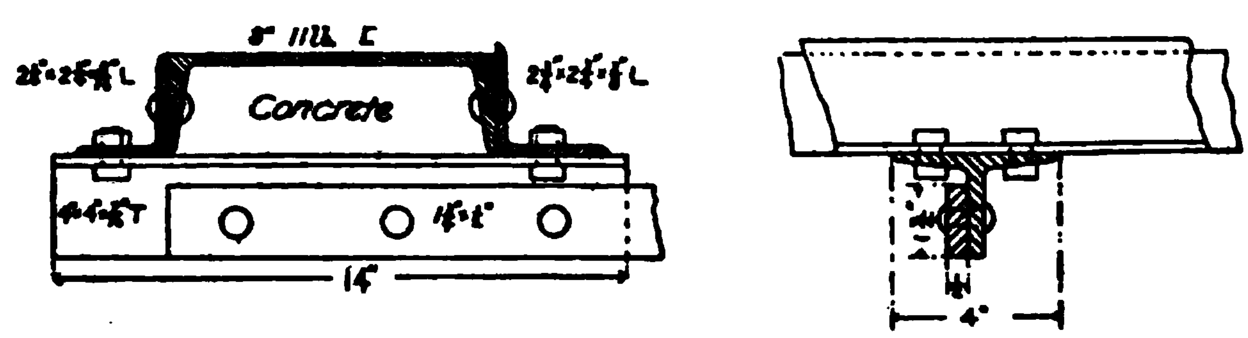


FIG. 67.—CROSS SECTION OF STEEL WHEELWAY.

for the road, and Fig. 68 shows the details of the rail. The two rails are tied together by a $2\frac{1}{2}\times\frac{3}{8}$-inch bar riveted to two short pieces of $4\times3\times\frac{5}{16}$-inch angles which are bolted to the inside and the outside flanges of each rail. These gage-ties are spaced 15 feet apart. The rails are spliced end to end by the breaking of the joints of the several members composing a wheelway. Owing to the impossibility of filling the underside of the rail with concrete,



Cross Section of Rail. Detail of Tie Connection

FIG. 68.—DETAILS OF STEEL WHEELWAY.

the road was not built according to the cross section shown in Fig. 67; and consequently the rail was filled with a $2''\times8''$ pine timber. About 2,100 feet of double track was laid where the traffic was exceptionally heavy. This traffic consisted chiefly of wagons heavily laden with packing-house products. The rails were embedded in crushed limestone, and the space between them was filled with the same material. The work was done under the direction of a competent railroad engineer.

Within two or three weeks after completion, the following defects had appeared: 1. The inner edge of the rails was considerably depressed, owing to the compression of the crushed stone under the rail. 2. The face of the rail was concave except

where the gage-ties were attached, owing to the compression of the wood under the rail and to the spreading apart of the lower edges of the rail. 3. The rails were bowed horizontally outward, between the gage-ties, owing to the wedging action of the crushed stone between the rails. 4. Pieces of broken stone were continually loosened by the horses' feet and kicked upon the face of the rail, where they were ground to powder.

At this stage, sawed railroad ties were inserted 3 feet apart, and both flanges of the rails were spiked to the ties. After these repairs, the rails maintained their position reasonably well, but deflected between the ties; and bad ruts soon formed adjacent to the rails, and the crushed stone was ground up to such an extent that the rail was almost hidden by dust. It is conceded that this steel wheelway has not been a success. It has been taken up.

397. *Advantage of Steel Wheelways.* The chief advantage claimed for the steel wheelway is a reduction of traction and a consequent permissible increase of the load. The advocates of this form of roadway frequently compare the tractive resistance per ton on earth roads with that on railroads, and conclude that a horse can draw ten to twenty times as much on a steel wheelway as upon an earth road. This conclusion is erroneous for two reasons: 1. The steel wheelway advocated is not anything like as rigid and smooth as the ordinary railroad track, nor can it be kept nearly as clean. A thin film of dirt on the rail materially increases the tractive power—compare lines 16 and 17 of Table 8, page 29. 2. In the above claim as to the relative loads upon a steel wheelway and an earth road the effect of the footing upon the load a horse can draw is not considered. Unless the space between the rails is paved, a steel wheelway would be but little better than an earth road in a muddy time—when the advantages of a steel wheelway are most desired. Further, unless the space between the rails is paved, it will be impossible for vehicles to turn on or off the wheelway except at specified points. If turnouts are frequent, the expense will be great; and if they are infrequent the inconvenience will be great. Therefore, it is safe to assume that any successful wheelway must have a permanently hard surface between the rails; and consequently the tractive resistance of a wheelway should be compared, not with an earth road, but with

a road having the same surface as that between the rails of the wheelway.

Tests made by the author on the steel wheelway described in § 396 (see Table 8, page 29) show that the tractive resistance of such a road under the most favorable condition is more than that of a good brick or macadam surface; and that under ordinary conditions it is about the same as that of a new plank road, or an ordinary brick pavement with concrete foundation, or a specially dressed granite-block pavement. The force of traction on the steel wheelway is surprisingly large, and is doubtless due to the deflection of the rail as a whole and also of its surface immediately under the wheel, the wheel being continually compelled to climb a grade. In the light of these tests, it must be concluded that unless the rail is very rigid and is kept clean, the reduction of tractive power will not be very great. If the wheelway is made rigid, the cost of construction will be considerably increased; and if the rail is to be kept clean, the space between the rails and adjacent to them must be covered with a practically indestructible surface which must be frequently swept.

In considering the relative tractive power required on different road surfaces, it should not be forgotten that the disadvantages of a grade increase as the tractive resistance decreases. For example, if on a steel wheelway the resistance is 20 pounds a ton, a 1 per cent grade will double the resistance; while on a macadam road having a tractive resistance of 40 pounds a ton, a 1 per cent grade will increase the resistance only one half; and if the tractive force required on the macadam is 80 pounds a ton, a 1 per cent grade will increase the resistance only one fourth. In other words, in the above illustration a horse can draw only half as much on a level steel wheelway as up a 1 per cent grade, while on the first macadam road he can draw two thirds and on the second eight tenths as much up the 1 per cent grade as on the level. Therefore the advantage of steel wheelways in decreasing the force of traction can be obtained only when the wheelway is level or nearly so.

398. It is sometimes claimed that a steel wheelway makes a very durable road. As far as the steel rails are concerned, this is true; but it is not true of the surface adjoining the rails—what-

ever that surface. It is often assumed that the space adjoining the steel rails is to be paved with crushed stone. If this is done, vehicles in turning out to pass each other will certainly wear ruts adjoining the rails, as is shown by the ruts worn in the most durable pavements by vehicles turning on and off of street-car rails. Further, it is well known that tracking is one of the most effective causes of the destruction of crushed-stone roads, partly because the stones loosened by the horses' feet are not rolled into place by the wheels; and consequently the horses' feet will be more destructive on a macadamized steel wheelway than on an ordinary crushed-stone road. It has been estimated (§ 372) that the wear of ordinary macadamized roads due to the horses' feet is 1½ to 3 times as much as that due to the wheels. In consideration of the tendency of the wheels to produce ruts adjacent to the rails, and of the failure of the wheels to roll into place the stones loosened by the horses' feet, it is probable that a steel wheelway will at best add nothing to the durability of the adjoining macadam.

If the space between the rails is paved with a more durable material than macadam, the cost will be unreasonably great. The question of cost will be considered in the next section.

399. *Disadvantages of Steel Wheelways.* The most serious objection to a steel wheelway is that if it does not have a permanent footway for the horses it is least effective in a muddy time, i. e., when most needed; and if it does have a permanently hard surface between the rails, the cost is unreasonable.

If a steel wheelway is laid in a crushed-stone road, the additional cost will be (1) the cost of the metal, (2) the cost of placing the metal, including the increased cost of compacting the crushed stone, and (3) the increased cost of maintenance.

1. The steel wheel shown in Fig. 67 and 68, page 265, will require about 121 tons of steel for a mile of single track. The cost, delivered, would probably not be less than $40 a ton, in which case the metal for a mile of single track will cost $4,840. In this connection it should not be forgotten that experience with the above described steel wheelway shows that the rails are too light for any considerable traffic.

2. The cost of placing the metal will vary considerably with the design of the track and with the thoroughness with which the

stone is compacted around the rails. Only practical experience can determine how much labor will be required to form an even bed for the rails, to bolt together the rails and attach the gage-ties, and to consolidate the stone around the rails and the ties, but it would probably amount to at least $500 per mile. There are 14,000 feet of lumber in a mile of single track like that shown in Fig. 67, which in place will cost at least $25 per thousand feet, or $350 a mile. If concrete is employed, it will cost two or three times as much as the lumber. The total cost of placing the metal will thus be at least $850 a mile of single track.

3. It is impossible accurately to estimate the cost of maintenance. Only experience can determine the amount of labor required to prevent low joints and to fill up the horse paths and the ruts next to the rails. However, it seems reasonable to estimate that these expenses will amount at least to as much as the maintenance of an ordinary crushed-stone road to carry the same traffic; and hence in this comparison such expense may be neglected.

The total cost of the wheelway proper would then be $4,840 + $850 = $5,690 a mile over and above the cost of a crushed-stone road. What are the advantages to be derived from this expenditure? Only the possibility of a slight decrease in the tractive power. In considering the effect of this decrease, it should be remembered that it is of value only to fully loaded teams; and, further, that such an advantage would accrue only to such fully loaded teams as haul their load from start to finish upon the steel wheelway or other equally good road. The above cost would then be incurred for a very slight advantage to a very small part of the traffic, and therefore there are few circumstances under which the cost of a steel wheelway would be justifiable.

400. A single-track wheelway is undesirable, since vehicles must turn out frequently in meeting each other, and since either the slowest team will regulate the speed of the procession or the faster teams must turn out and go around. Turning out is difficult on account of the flange on the rail; and, further, the sliding of a wheel against the flange causes the opposite wheel to tear up the macadam surface. A double-track wheelway would only partially remove the above objections; and ordinarily where there is traffic enough to justify a double-track wheelway, a uni-

versal wheelway, i. e., a first-class pavement, should be built. On the double-track steel wheelway described in § 396, more than half of the vehicles turned out and went around the slow ones.

401. Another objection to any wheelway is that owing to the comparatively narrow space between the rails, the horses are compelled frequently to step upon the rails, the smooth surface of which interferes with the footing of the horses. This in a considerable measure neutralizes the advantage of a smooth track for the wheels. Teamsters using the steel wheelway described in § 396 strongly urged this objection, and in addition claimed that the projecting flange injured the frog of the horse's foot.

402. Still another objection to a wheelway is that the gage of vehicles varies considerably, and consequently either the face of the rail must be very wide—a requirement which adds expense,—or some vehicles can not be accommodated. In almost any large city, wagons are found with gages varying from 4 feet 8 inches to 6 feet.

403. The conclusion is that trackways are out of date; that they are more expensive and less effective than good macadam roads; and that for a country road where an ordinary macadam surface does not suffice, a first class pavement or a railroad should be built.

404. Clay-block Wheelway. It has frequently been proposed to build a wheelway of burned clay blocks. After the above discussion of steel wheelways, little need be said concerning this form. The blocks proposed are usually comparatively small, and would probably be difficult to place and to keep in line, particularly during freezing and thawing weather; they would probably lack durability; and the cost of such construction would probably be unreasonably great. The wheelway referred to in § 394 was built by an accomplished road builder where such roads were common, and therefore the construction was presumably suited to the service; and if this be true, no cheaply constructed wheelway can render efficient service.

405. BURNED-CLAY ROADS. In the Mississippi Valley, where gravel or rock suitable for ballast must be transported considerable distances, the railroads have been experimenting in recent years with burned-clay ballast, and it has frequently been proposed

to use that material instead of crushed stone for building wagon roads.

Almost any clay, except one containing considerable sand, can be used for this purpose; but one containing considerable organic matter, though it burns more easily and is lighter to handle, gives a more friable product. The so-called gumbo soil is much used for burned-clay ballast. The best clay for this purpose is usually found in bottom lands, and is distinguished by being very plastic, very fine grained, and quite tenacious—in its native condition, the very worst material of which to build a wagon road. The burning is done in ridges often 2,000 to 4,000 feet long, the clay being mixed with nut or slack coal. As a rule, the better grades of coal are more satisfactory, since the fire burns better and is not so likely to be put out by rains. Wood is used to start the fire. The railroads usually locate the kiln alongside of a track, and handle the material almost entirely by steam power. The clay is loosened by a plow attached to a locomotive, and falls upon a conveyor which elevates it to the ridge-like kiln. The coal is shoveled directly from the cars upon the kiln. Successive layers of clay and coal are added on one side of the ridge, while on the other side the burned clay is allowed to cool. In this way the pit advances sidewise a few feet each day. About 1,000 cubic yards a day can be burned in a kiln 4,000 feet long, 50 men and a locomotive being required to do the work.*

The cost of burning depends upon the weather, the cost of coal, and the facilities for draining the kiln. Under favorable conditions, a ton of coal will burn 4 to 6 cubic yards of clay. The cost of burned clay when burned as above varies from 75 cents to $1.00 a cubic yard on board cars. The labor cost exclusive of train service is about 50 cents a cubic yard.

406. The burned clay or gumbo used by railroads for ballast is a reddish, gravelly material, the fragments of which are angular, very porous, and usually about as hard as soft burned brick. The chief merit of this material for railroad ballast is its porosity—just the opposite of the quality desired for the surface of a wagon road. It is not known that this material has been tried for wagon

* *Engineering News*, Vol. 30, p. 399–400.

roads, but it will probably prove to be too soft and friable, and too deficient in binding power (§ 277). The localities in which clay suitable for burning is available, are those having a very sticky soil, which, when carried upon the road, would probably speedily pull to pieces even the best stone roads. In several respects the conditions necessary for the successful use of burned clay as railroad ballast are very different from those required for its economic use as a surfacing material for wagon roads; and it is at least doubtful whether fragments of burned clay will ever come into considerable use for wagon roads in any locality.

It is possible that clay burned as brick may be employed for country roads where there is a scarcity of gravel or suitable stone, in which case the road will be constructed practically as a brick pavement—see Chapter XIV. The advantage of a brick roadway over one made of fragments of burned clay is that with the former the clay can be burned more thoroughly, more uniformly, and more economically in a permanent kiln than in a temporary pit; and bricks are of a better form for road building than irregular fragments.

407. CONCRETE ROADS. Concrete is much used for the foundation of pavements (see Art. 2, Chapter XII), and in a few cases it has been used for the wearing surface. In Philadelphia many alleys are paved with hydraulic cement concrete, in which case it is laid as for sidewalks (§ 933–57); and in several cities where asphalt or some of its substitutes have been used for a wearing surface on a foundation of concrete, when the surface coat has worn out the traffic has been allowed to come directly upon the concrete foundation.

This form of road surface is not likely to come into general use owing to its cost and slipperiness when laid as are sidewalks, and its cost and lack of durability when laid like the foundation of a pavement. Portland cement concrete is said to be used in preference to all other paving materials in Grenoble, France, and in several German cities, but such use must be under exceptional conditions.

408. For a consideration of tar-concrete and tar-macadam roads, see § 698–713.

409. SHELL ROADS. Around the Chesapeake Bay and on the coast of the Gulf of Mexico, oyster shells have been used to a

considerable extent for road purposes. They are spread loosely over the road and speedily become consolidated by the traffic. The shells have a high cementing power, but a very low resistance to crushing; and while they make a smooth road surface, it is speedily ground to powder, producing a disagreeable dust, and requiring the constant application of new shells to keep it from rutting. A shell road is suitable only for light driving.

At many points along the Atlantic and Gulf coast-lines, there are, under the mud flats and marshes, extensive beds of ancient oyster shells, which may be easily excavated and made available for road-building purposes.* In localities where the traffic is not heavy and where gravel or stone suitable for road coverings can not be procured except at considerable cost for transportation, oyster shells, either ancient or modern, afford a fairly good and cheap road-building material.

On the shores of the Chesapeake Bay it is common to build these roads 18 feet wide, the loose shells being 18 inches deep in the center and 9 inches on the sides. The shells cost about 2 cents a bushel, making the total cost of the road about $1,740 per mile (16½ cents per sq. yd.). Shells are used for paving in a number of cities of the Gulf coast, and such pavements often cost 50 to 70 cents a square yard.

410. SLAG ROAD. Blast-furnace slag from old-style iron furnaces has a glassy appearance, is very hard and brittle, and except for foundations is of little value as a road material, since it quickly grinds to fine dust. The slag from modern steel furnaces is comparatively light, has a sponge-like structure, and contains a large amount of lime. When used for roads this variety compacts very readily and forms an even and hard surface. Steel-furnace slag dust has a high cementing power.

Slag is used for road purposes only to a limited extent, and only near steel mills.

411. COAL-SLACK ROADS. Coal slack is sometimes used for road building where neither stone nor gravel is available at reasonable cost. The slack is friable and easily grinds to powder, but makes a fair road for light traffic. In many localities the large

* Professor Shaler in Fifteenth Annual U. S. Geological Report, 1893–94, p. 287.

quantities of slack are a burden, and could profitably be spread upon the roads. It is light, and therefore easily hauled.

412. Plank Roads. Plank roads were once somewhat common in the heavily timbered portion of the northern United States and of Canada. The first plank road on this continent was built in Canada in 1836. These roads are practicable only where timber is plentiful and cheap, where stone or gravel is scarce and expensive, and where there is little or no water or rail transportation and consequently a great demand upon wagon roads. Only a few plank roads are now in existence, but such roads have been advantageous in the development of a new country.

Plank roads are usually about 8 feet wide, and occupy one side of an ordinary earth road, the other side being used to turn out upon and for travel during the dry season. The method of construction most commonly followed is to lay down lengthwise of the road, two parallel rows of plank called sleepers or stringers, about 5 feet apart between centers, and upon these to lay cross-planks 3 to 4 inches thick and 8 feet long. The ends of the planks are not adjusted to a line, but form short offsets at intervals of 2 to 3 feet, to prevent the formation of long ruts at the edges of the road, and to aid vehicles in regaining the plank covering in turning onto the road. The planks were often covered with gravel, sand, or loam to protect them from wear.

When kept in repair, plank roads make a comparatively smooth roadway possessing some advantages for both heavy and light traffic, but the planks are very likely to be displaced—even when spiked down as was sometimes done,—and are also likely to be floated away. Being alternately wet and dry, the plank rotted rapidly, and at best did not last more than five years, and sometimes only two.

Most plank roads were toll roads, and often paid a handsome profit to their owners.

413. Corduroy Roads. Corduroy roads are make shifts employed in a new timbered-country to carry a road over a swamp or marsh which can not be drained without undue expense. They are built by laying logs side by side across the roadway, the spaces between the larger poles being leveled up with smaller ones. With sufficient care, such roads can be made fairly smooth when new;

but they are usually exceedingly rough, and grow worse with age. Although corduroy roads afford means of crossing swamps which at times are otherwise utterly impassable, their retention upon a road of any considerable travel is usually unjustifiable.

414. Charcoal Roads. Where timber was very plentiful and gravel scarce, a fair road for light traffic has been made by felling and burning the timber, and covering the road with the charcoal. Poles from 6 to 16 inches in diameter are piled lengthwise in the center of the road—5 feet high, 9 feet wide at the base, and 2 feet on top—and covered with straw and earth. The earth required to cover the timber is taken from the side ditches. When charred, the earth and charcoal are spread over a width of 15 feet, leaving it 2 feet thick at the center and 1 foot at the sides, although a depth of 15 inches at the center and 10 inches at the side makes a fairly good road.

The charcoal is soft and friable, and hence should be covered with a thin layer of gravel for greater durability, and to prevent it from blowing and washing away, or from catching fire from matches or lighted cigars thrown upon the surface. The earth covering of the charcoal pit is a fair road material and may be used as a top-dressing for the charcoal.

Charcoal roads cost from $500 to $1,500 per mile, and of course are feasible only when the timber has no market value, and must be got rid of before the land can be devoted to agricultural purposes.

CHAPTER VII.

EQUESTRIAN ROADS AND HORSE-RACE TRACKS.

416. The prime object in the construction of ordinary roads is to secure a firm unyielding surface that will give a low tractive resistance and be durable and easy to maintain; while in the class of roads to be considered in this chapter, the chief purpose is to secure a road that shall be easy on the horse and enable him to attain a high speed.

ART. 1. EQUESTRIAN ROADS.

417. Equestrian Roads or Saddle Paths are ways designed especially for horse-back riding.

418. WIDTH AND CROWN. Equestrian roads are seldom made narrower than 12 feet, and in populous districts are often 20 to 30 feet wide. The crown of the narrower road is about 3 inches and of the wider 6 inches. The material of the surface being light and loose, the grade both transverse and longitudinal should be slight, as otherwise there is danger of the surface being badly washed.

419. DRAINAGE. On the ordinary road or pavement, the surface is compact and acts as a roof to shed the rain water into the side ditches; but on an equestrian road, the surface is loose and absorbent, and therefore the drainage of the road-bed is even more important than that of an ordinary road or pavement.

The ground should have thorough underdrainage—either natural or artificial. Since the surface of the road must be loose and porous, it can not have any considerable transverse slope for fear the surface material will be washed away; and therefore to facilitate the drainage, the subgrade should be crowned. In

constructing a wide bridle path, it may be necessary to form the subgrade and lay tile as shown in Fig. 69; but ordinarily this

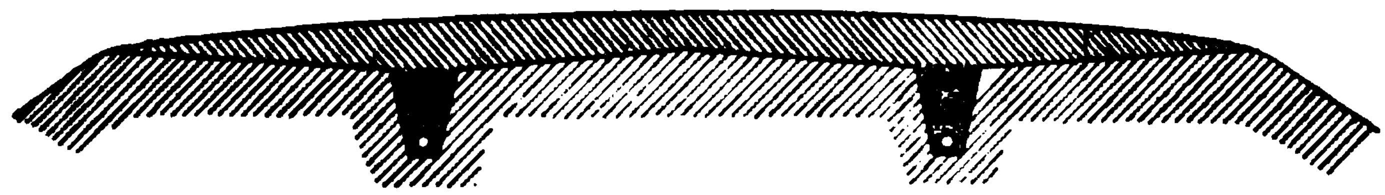


FIG. 69.—FORM OF SUBGRADE OF A WIDE EQUESTRIAN ROAD.

is not required, one of the constructions described below being sufficient.

If the soil is a close retentive clay, a regular telford foundation or a layer of rubble should be placed on the subgrade. The latter was employed in the riding paths of Central Park, New York City, with entire satisfaction. A layer of 3 or 4 inches of clean coarse gravel should be placed upon the telford or rubble foundation, to prevent the surfacing from working into the foundation.

If the soil is somewhat porous, the telford or rubble foundation is not required; and then the layer of gravel is placed directly upon the subgrade, to aid the drainage and to keep the fine surface material from becoming mixed with the soil below.

420. SURFACE. Since no vehicular traffic is to be provided for, a smooth hard surface is not required; but it is necessary that the surface shall be somewhat soft and loose, so as to protect the horse from injury and to make the riding easy and agreeable. The surface must be such as not to become greatly impaired during wet weather nor be subject to material changes in dry weather, and not be acted upon by frost. It should be neither too rigid nor too yielding, but should be of such consistency as to afford the easiest movement of horse and rider, and at the same time be reasonably durable and economical to repair and maintain. Loam, sand and clay, gravel, and tan bark have been used. Loam would probably be most suitable, if it could be maintained at all times in its best condition. In the South Side Parks of Chicago, ordinary black earth laid on a sandy subsoil and covered with a thin dressing of detritus from macadam and gravel roads gives very satisfactory results, although the roads become soft in very wet weather.

Ordinarily equestrian roads are surfaced with 2 to 3 inches of coarse sand or fine gravel practically free from earthy matter.

After being spread evenly with rakes, it is lightly sprinkled and then rolled with a light roller just enough to keep the horses' feet from sinking into it. If the surface has a tendency to pack too hard under use, a little clean coarse sand strewn over the surface will counteract it; and on the other hand, if the surface is too loose and yielding, the addition of a small quantity of clay or loam with sprinkling and rolling will correct the defect.

ART. 2. HORSE-RACE TRACKS.

421. An engineer is occasionally required to lay out and construct a horse-race track, and therefore a consideration of this subject is not out of place here.

422. THE FORM. The best form for speed would be a straight level track, since on it every exertion of power by the horse would be employed in producing speed; but such a form is objectionable, since the start and finish can not be observed by the same spectators nor be timed by the same judges. If the track is curved, centrifugal force is developed; and unless the speed corresponds exactly to the super-elevation of the outside of the track, i. e., to the transverse slope of the surface, part of the exertion of the horse will be consumed in overcoming centrifugal force, and consequently the maximum speed will not be attained. If the race is side by side, centrifugal force is of no great consequence: but where the race is for a record or against time, it is important to have every condition favorable,—especially when seconds are divided into fifths.

The intensity of centrifugal force varies inversely as the radius of curvature and directly as the speed; and therefore to secure a minimum effect of centrifugal force the amount of curvature should be as small as possible, and the radius of curvature should be as large as possible. The fastest track that permits the race to terminate near the starting point, is two straight lines crossing each other at an angle and being connected at one extremity by a circular arc of long radius, since this track gives a large radius and minimum curvature. This form is known as a kite track (see § 427). The next best form is an oval, on which the races begin and end at the same point. An oval contains 360° of curvature,

while a kite track of the same length has considerably less curvature. The most unfavorable condition for speed is one or more times around a small oval or circle.

The kite-shaped track requires more ground than the oval, does not afford the spectators quite as good a view of the race, and does not permit races longer than once around the track. The half-mile oval requires less ground than the mile oval, gives the spectators a better view of the race, and is favorable for races longer than once around the track. A circular track is not so good as an oval, since a straight stretch is desirable for the start and finish. Half-mile oval tracks are most common, mile ovals are next, and kite tracks are least common. Straight tracks are constructed only for fast pleasure driving, when they are usually termed speedways.

423. The usual forms of tracks and the methods employed in laying them out will be described, and then some designs by the author will be presented.

424. Standard Oval. *Mile Track.* Fig. 70 shows the usual form of the mile oval, the only variation being in the width of the track itself. The dotted line represents the pole line, the line upon which the distance is measured, which is universally 3 feet outside of the inner edge of the track. The wire

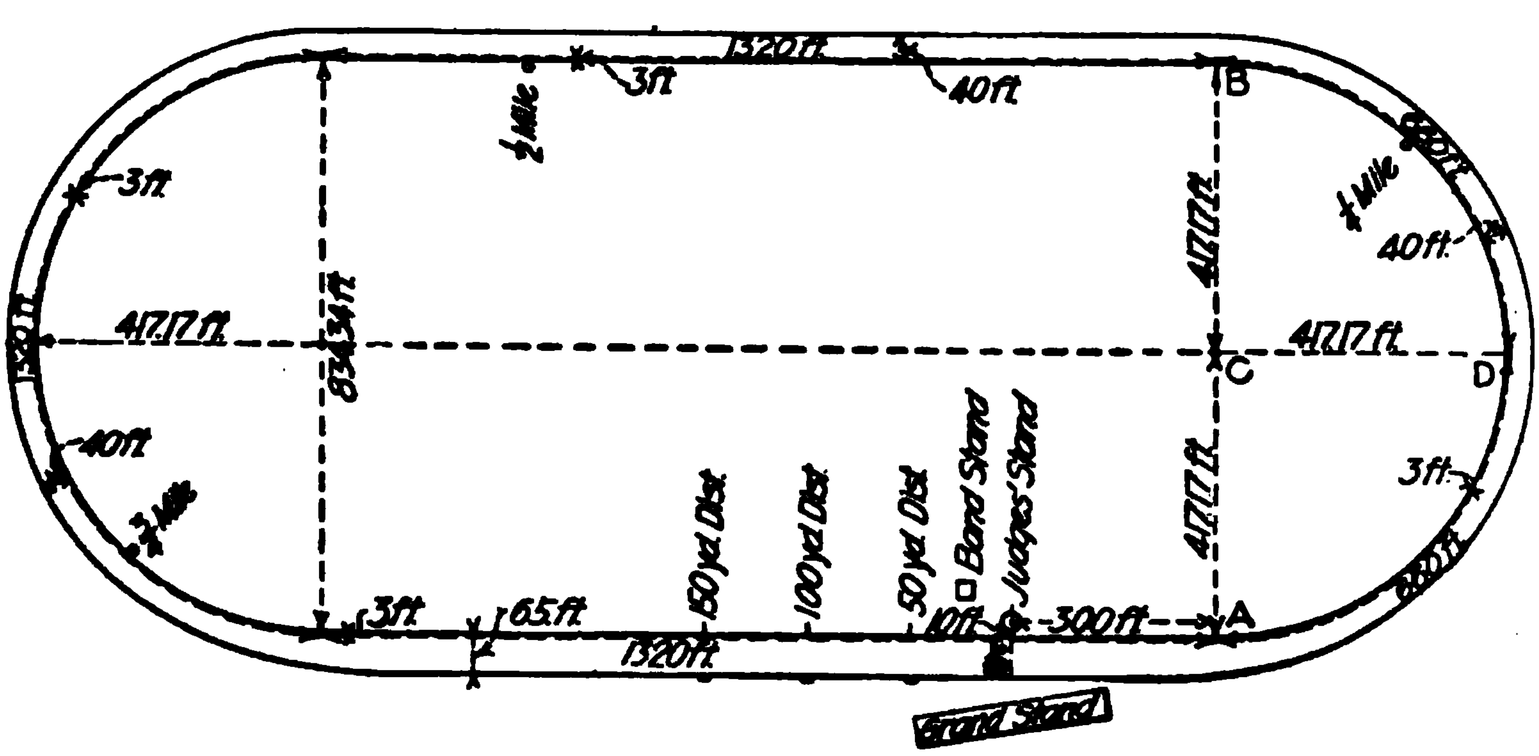


FIG. 70.—STANDARD OVAL MILE TRACK.

is usually 300 feet from the beginning of the curve, *A*. The ¼, ½, and ¾ mile points are indicated by poles set at the inside

edge of the track, in such a position that a line from the judges' stand cuts the pole line at the proper point.

In constructing the track, it is more convenient to mark the inner edge of the track than the pole line. The semi-circular ends may be laid out by any of three methods:

1. *Amateur's Method.* Fasten one end of a wire of a length equal to the radius, at the center of the semi-circle, and swing the free end around and establish as many points on the inside edge of the track as are desired. A wire is better than a string or rope, since it will stretch less.

2. *Surveyor's Method.* Establish eight points in each quadrant by laying off the lines and distances shown in Fig. 71. This

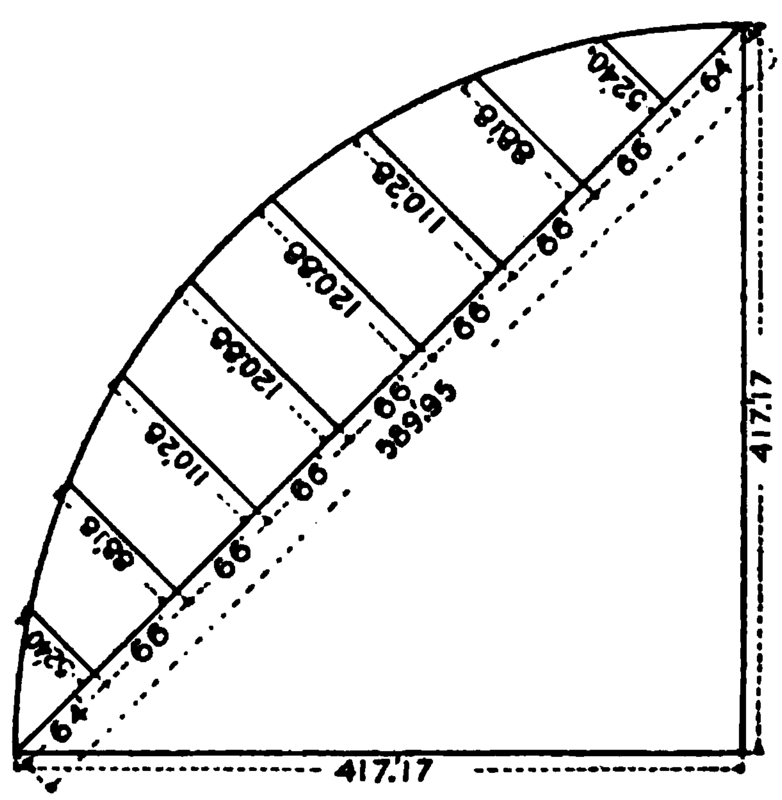


FIG. 71.—SURVEYOR'S METHOD FOR MILE TRACK.

method gives points on the curve about 66 feet apart, and is designed especially for the land surveyor, who ordinarily uses a 66-foot chain or steel tape.

3. *Engineer's Method.* Set a transit at the tangent point (A, Fig. 72), and lay off successively the equal angles a_1, a_2, a_3, etc., as shown in Fig. 72, and measure, also successively, the equal chords $A\,E$, $E\,F$, $F\,G$, etc. The angle a may have any value, provided the length of the chord is made to correspond; but for convenience, a should be an aliquot part of 90°. Table 27, page 281, gives several values of a and the corresponding values of the chord and also of the arc.

425. The outside edge of the track need not be laid out accurately. It is sufficient to set a flag pole at the center of the semicircle and measure from the inside edge in the line of the radius. The track shown in Fig. 70, i. e., the standard mile track having

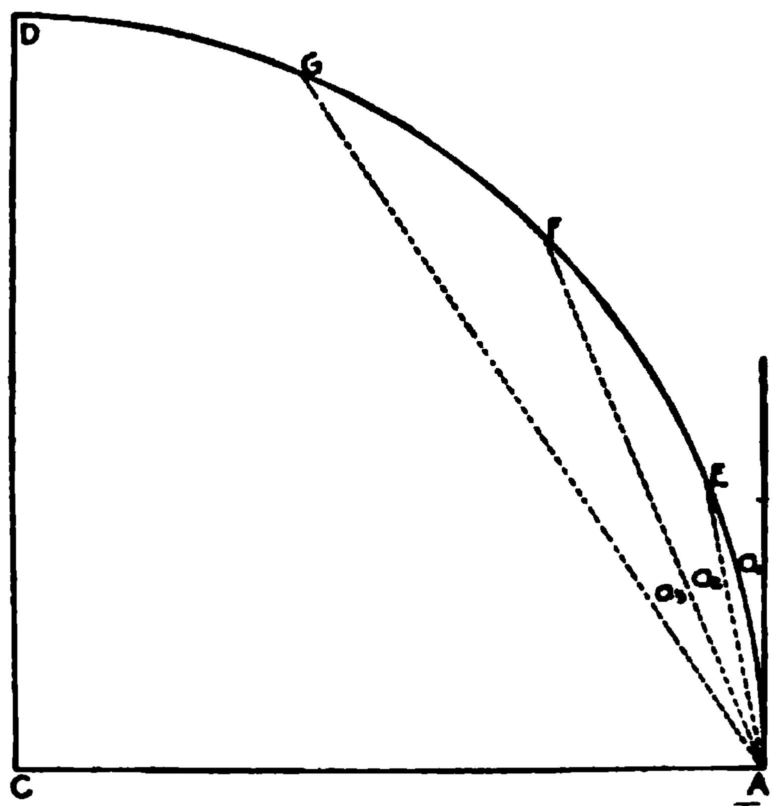


FIG. 72.—ENGINEER'S METHOD OF LAYING OUT CURVE.

a home-stretch 65 feet wide and the remainder 40 feet wide, requires a rectangle of ground 2,240 × 945 feet, or about 48.5 acres, for the track alone.

TABLE 27.

DEFLECTION ANGLES AND CHORDS FOR STANDARD OVAL MILE TRACK.

Ref. No.	Deflection Angle.	Length of the Chord.	Length of the Arc.	Number of Points on the Semi-circle.
1	1½°	21.84 ft.	21.84 ft.	60
2	2°	29.15 "	29.15 "	45
3	2½°	36.40 "	36.41 "	36
4	3°	43.67 "	43.69 "	30
5	4½°	65.46 "	65.53 "	20
6	5°	72.72 "	72.81 "	18
7	6°	87.22 "	87.38 "	15
8	7½°	108.91 "	109.22 "	12

426. *Half-mile Track.* Fig. 73, page 282, shows the usual half-mile oval, the only variation being in the width of the track. The dotted line represents the pole line, the line upon which the distance is measured, and is always 3 feet outside of the inner edge of the track. The wire is usually 170 feet from the beginning

of the curve. The semi-circular ends may be laid off in any of three ways:

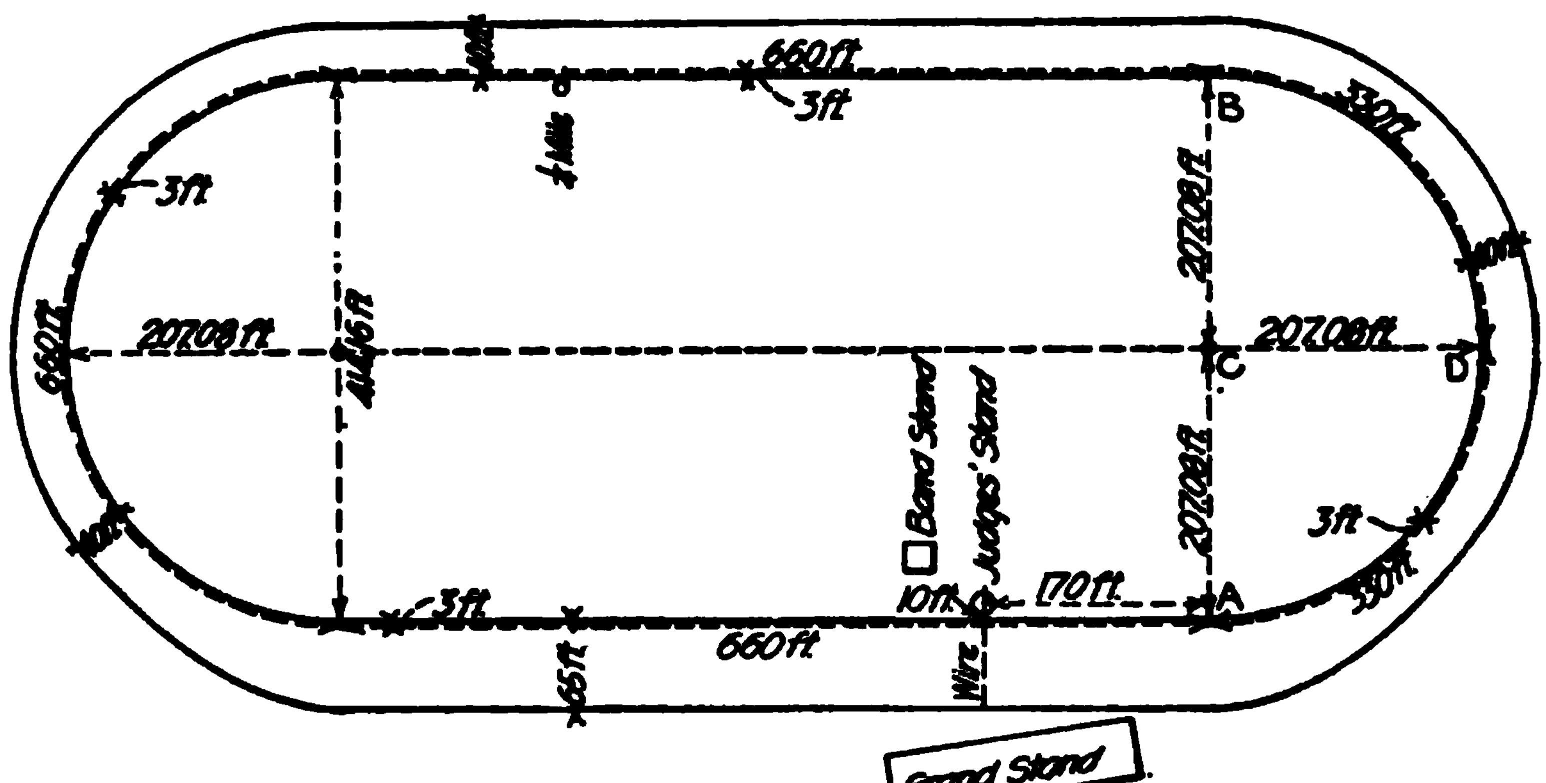


FIG. 73.—STANDARD HALF-MILE OVAL TRACK.

1. *Amateur's Method.* Fasten one end of a wire of a length equal to the radius, at the center of the curve, and with the other mark as many points as desired on the inside edge of the track.

2. *Surveyor's Method.* Establish five points by laying off the lines and distances shown in Fig. 74.

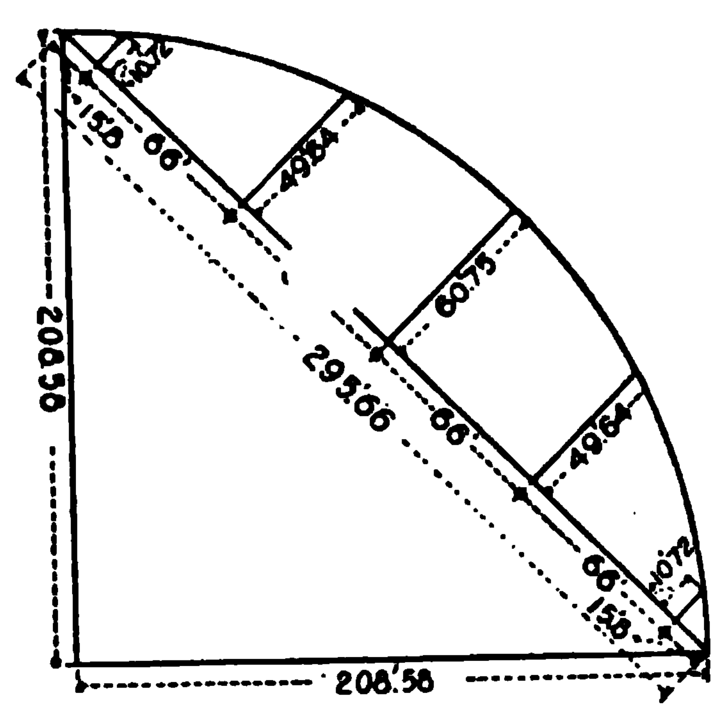


FIG. 74.—SURVEYOR'S METHOD FOR HALF-MILE TRACK.

3. *Engineer's Method.* Set a transit at the tangent point (A, Fig. 72, page 281), and lay off successively the equal angles a_1, a_2, a_3, etc., and the equal chords $A\,E$, $E\,F$, $F\,G$, etc., as shown in Fig. 72.

Table 28 gives various deflection angles and the corresponding chords, any pair of which may be employed.

TABLE 28.

DEFLECTION ANGLES AND CHORDS FOR STANDARD HALF-MILE TRACK.

Ref. No.	Deflection Angle.	Length of the Chord.	Length of the Arc.	Number of Points on the Semi-circle.
1	3°	21.83 ft.	21.84 ft.	30
2	4½°	32.74 "	32.77 "	20
3	5°	36.37 "	36.41 "	18
4	6°	43.61 "	43.69 "	15
5	7½°	54.45 "	54.61 "	12
6	9°	65.26 "	65.53 "	10

The track shown in Fig. 73, i. e., the standard half-mile oval with a home-stretch 65 feet wide and the remainder 40 feet wide, requires a rectangle of ground 1,060 × 525 feet, or a trifle over 13 acres.

427. Kite Track. Fig. 75 shows the form of kite track

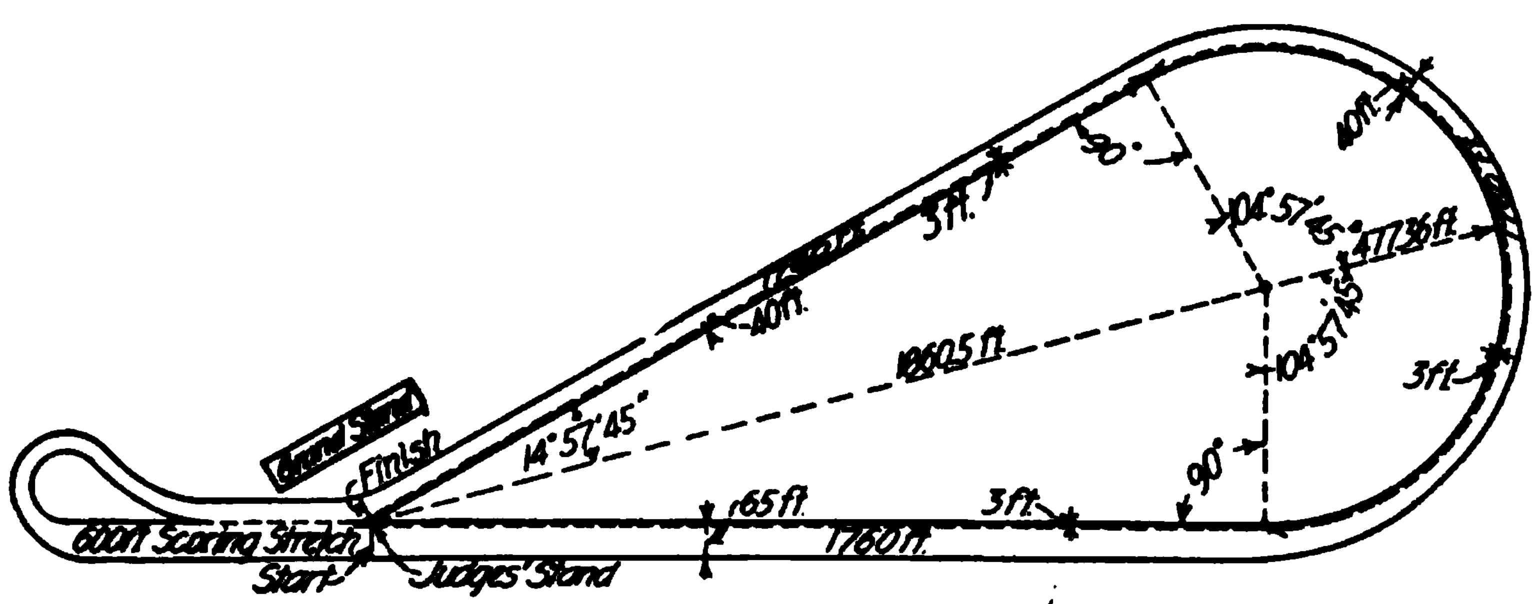


FIG. 75.—KITE TRACK.

introduced at Independence, Iowa, in 1890. The larger circular end may be laid out with a wire used as a radius, or by the measurement of the lines shown in Fig. 76; but for somewhat obvious reasons, the method described in the succeeding paragraph is the best.

The curve could be laid out by setting off equal deflection angles and measuring the corresponding chords as was explained in paragraphs 3 of § 424 and § 426; but in this case the central angle contains fractional degrees, and hence the deflection angle would be

inconvenient both to compute and to set off on the instrument. Therefore it is better to lay out the curve by the method usually employed for railroad curves, i. e., by successive 100-foot chords with a fractional chord at the end. The degree of the curve is 12° 0′ 11″, and hence the deflection angle for a 100-foot chord is 6° 0′ 5½″ or practically 6° 0′. The arc for a 100-foot chord is 100.183 feet, and hence the number of 100-foot chords is 17.4580 (=1,749÷100.183); in other words, there will be seventeen 100-foot chords and a chord of 45.80 feet at the end.

The dimensions of the small loop are of no importance, as it is used only for starting and slowing up; and no information is available as to the size in this particular case. In some tracks, the small loop is formed by prolonging the two tangents beyond their intersection and connecting them by a circular arc, thus making a track somewhat like a figure 8 with one loop very much smaller than the other. The form shown in Fig. 75 requires a rectangle of ground 2,900×1,060 feet or about 70.5 acres.

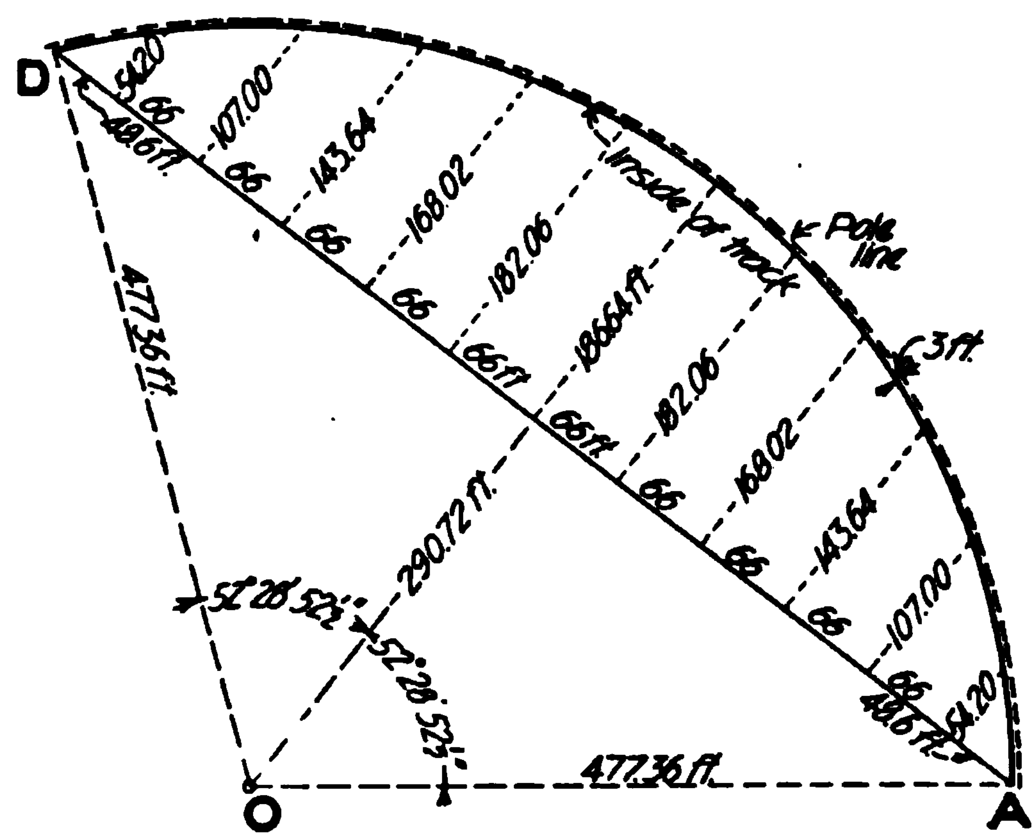


FIG. 76.—SURVEYOR'S METHOD OF LAYING OUT KITE TRACK.

428. The proportions of the kite track are susceptible of considerable variation. In Fig. 77, let A be the apex, B the starting point, and Z the finish. Then $B\ D\ E\ F\ Z=5{,}280$ ft.; or $B\ D\ E=$ 2,640 ft. Call the distance from the apex to the starting point x, i. e., $A\ B=A\ Z=x$ ft. Then

$$(T-x)\ R\ a \text{ arc } 1^\circ=2{,}640, \quad \dots\dots \quad (1)$$

which easily becomes

$$R\,(\cot a + 0.01745\,a^\circ) = 2{,}640 + x. \quad . \quad . \quad . \quad (2)$$

This is a perfectly general equation, and shows that x and either R or a may be assumed arbitrarily. Equation (2) may be used

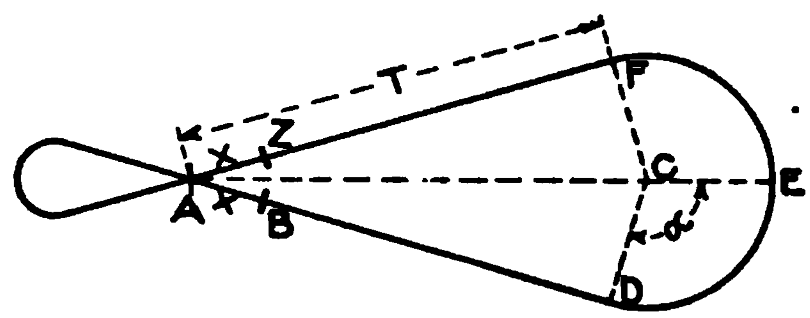


FIG. 77.—GENERAL FORM OF KITE TRACK.

also to deduce to dimensions of the small loop, in which case either R or the length of the curve must be assumed, a being the same as for the large loop, and $x = 0$.

The kite track is two or three seconds faster than an oval of the same length; but it is not satisfactory to the spectators, and consequently is not much used.

429. Oval Track with Easement Curves. All of the three preceding forms are defective in that the track changes instantly from a straight line to a circle of comparatively short radius. It is impossible for a horse at any considerable speed to change instantly from a right line to a curve; and if the change is made in a comparatively short space, a severe shock is experienced and a considerable effort is required. The ideal race track should change gradually from the straight to the curved portion. It will be shown presently that on the curves the outer portion of the track should be higher than the inner edge, to facilitate the passage of the horse around the curves. This super-elevation is not required on the straight stretches. With the forms described above, it is impossible to secure at all points the proper amount of super-elevation. The total super-elevation can not be attained instantly; and if it begins on the straight portion and reaches the proper amount at the tangent point, it is an obstruction on the straight stretch; and if it begins on the curve and gradually increases to the proper amount, the first part of the curve does not have the needed super-elevation. Therefore the straight stretch of the track should be joined to the circular portion by a curve of uniformly varying curvature. This easing of the curves is not

common in race-track construction; but it is absolutely necessary on railroads, is very important in bicycle racing (see Chapter XX), and would be very beneficial on horse-race tracks.

Various curves for connecting the straight and the circular portions have been proposed, but the best is the transition spiral.* In this curve, the radius varies inversely as the distance along the curve.

430. *Mile Track.* Fig. 78 shows one quadrant of the inside

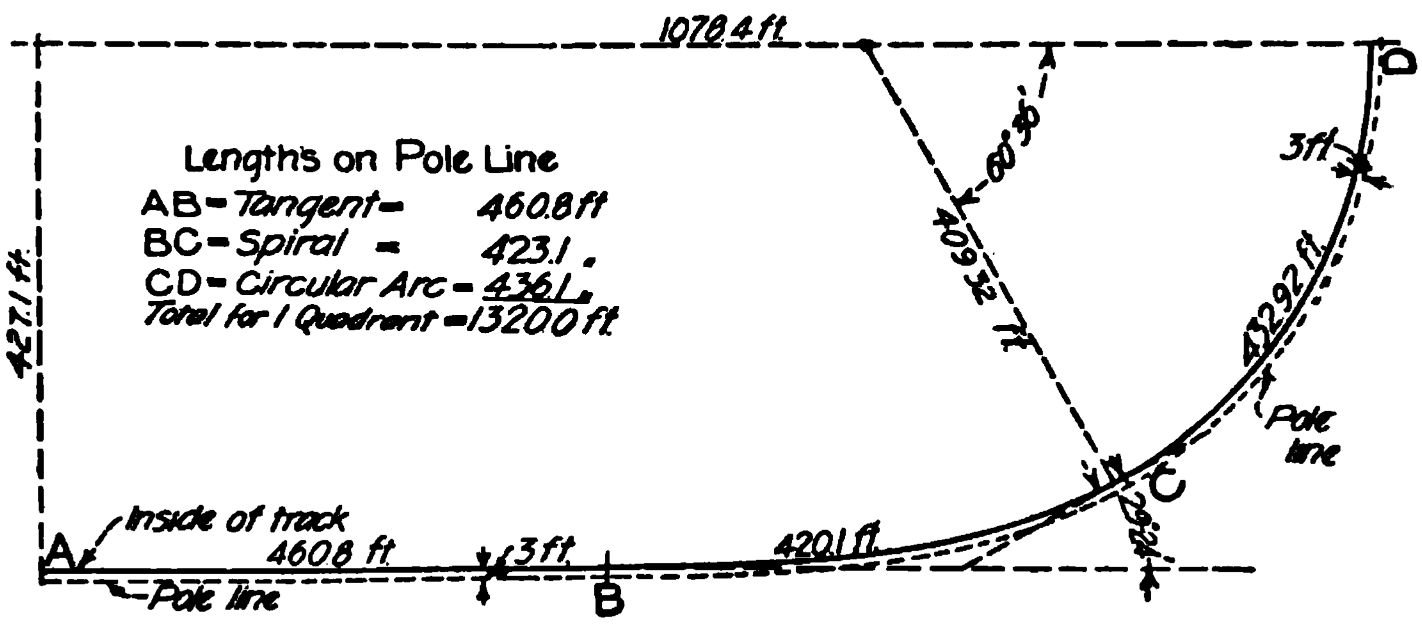


FIG. 78.—ONE QUADRANT OF MILE TRACK WITH TRANSITION SPIRAL.

curve of a mile oval with a transition spiral between the straight and the circular portions. Except for the easement curve, the track is substantially the same as the standard mile oval shown in Fig. 70, page 279.

Either of two methods may be employed in laying of the spiral—that by deflection angles and chords, or by rectangular co-ordinates. Table 29, page 287, contains the necessary data for the first method, and Table 30 those for the second. The point P.S. (point of spiral) in the tables is the point *B* in Fig. 78, and the point P.C.C. (point of compound curve) is *C* in Fig. 78.

The circular *CD* is most readily laid out by successive chords. The deflection angle for a 100-foot chord is 7° 0′ 59″ or practically 7° 1′. The arc for a 100-foot chord is 100.249 feet, and hence the number 100-foot chords is 4.3202 (=433.09÷100.245); that is to say, in the distance *CD* there will be four 100-foot chords and a chord of 32.02 feet at the end, or in the entire circular arc at one

*The Railroad Transition Spiral, by Arthur N. Talbot, 6″ × 4″, p. 110, 3d edition, 1901, Engineering News Publishing Co., New York.

end of the track there will be practically eight 100-foot chords and one chord of 64.04 feet.

TABLE 29.

CHORDS AND DEFLECTION ANGLES FOR LOCATING THE SPIRAL FOR THE INSIDE EDGE OF THE MILE TRACK.

Point on Spiral.	Distance from P.S. along Curve.	Deflection Angle at P.S. from Initial Tangent.
P.S.	00 ft.	0° 00′
1	100 "	0 33
2	150 "	1 15
3	200 "	2 13
4	225 "	2 48
5	250 "	3 28
6	275 "	4 12
7	300 "	5 00
8	325 "	5 52
9	350 "	6 48
10	375 "	7 48
11	400 "	8 52
P.C.C.	420.1 ft.	9 47

TABLE 30.

RECTANGULAR CO-ORDINATES FOR LOCATING THE SPIRAL FOR THE INSIDE EDGE OF THE MILE TRACK.

Point on Spiral.	Distance from the P.S. on the Tangent Prolonged.	Offset Perpendicular to the Tangent.
P.S.	00 ft.	0.0 ft.
1	100.0 "	0.97 "
2	149.9 "	3.27 "
3	199.7 "	7.75 "
4	224.5 "	11.04 "
5	249.2 "	15.11 "
6	273.8 "	20.11 "
7	298.0 "	26.05 "
8	322.0 "	33.08 "
9	345.6 "	41.19 "
10	368.8 "	50.54 "
11	391.4 "	61.10 "
P.C.C.	409.2 "	70.53 "

431. *Half-mile Track.* Fig. 79, page 288, shows one quadrant of the curve of the inside of the track of a half-mile track having a transition spiral, which except for the easement curve is substantially the same as the half-mile track shown in Fig. 73, page 282.

Tables 31 and 32, contain the data for the two methods of laying out the transition spiral. The deflection angle for 50-foot chords is 7° 1′ 00″. The arc for a 50-foot chord is 50.124

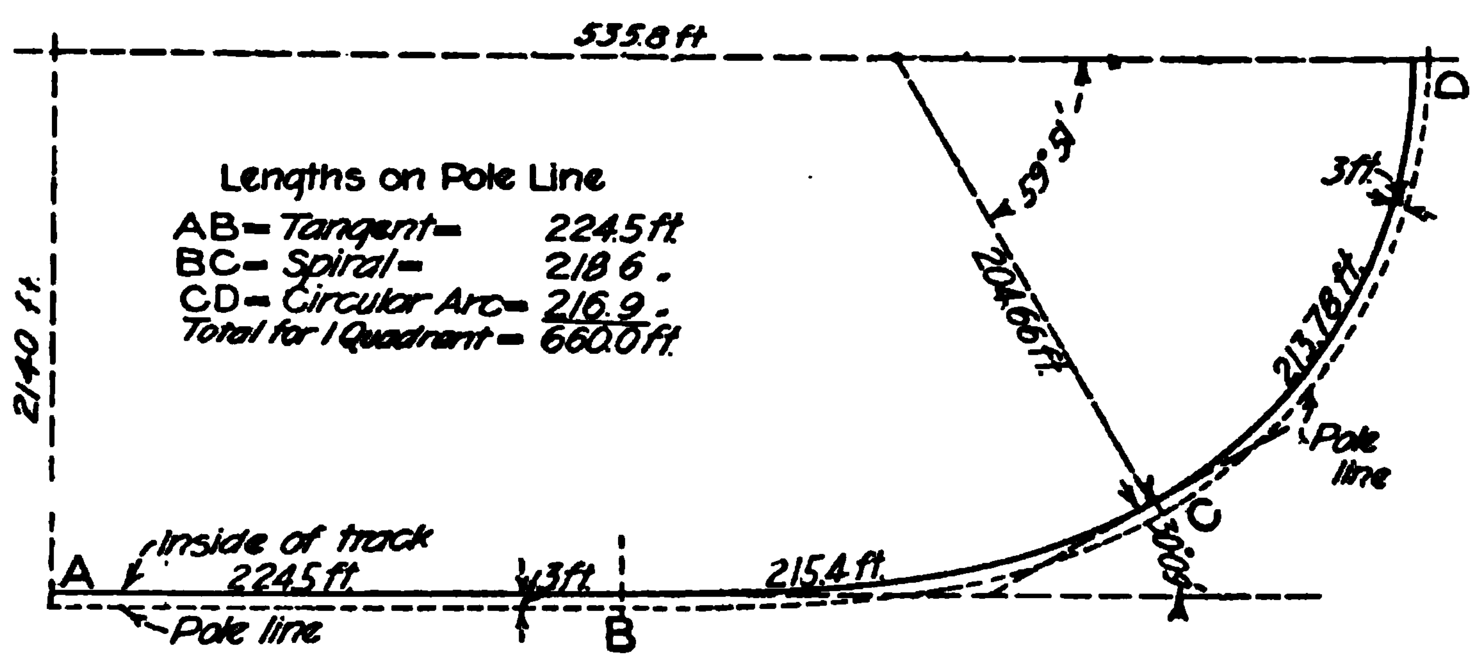


FIG. 79.—ONE QUADRANT OF HALF-MILE TRACK WITH TRANSITION SPIRAL.

feet; and hence the number of 50-foot chords in half the circular arc is 4.2567, or in the entire circular curve there are 4.2567, or four 50-foot chords and one chord of 12.83 feet.

TABLE 31.

CHORDS AND DEFLECTION ANGLES FOR LOCATING THE SPIRAL FOR THE INSIDE EDGE OF THE HALF-MILE TRACK.

Point. on Spiral.	Distance from P.S. along Curve.	Deflection Angle at P.S. from Initial Tangent.
P.S.	00 ft.	0° 00′
1	25 "	0 08
2	50 "	0 32
3	75 "	1 13
4	100 "	2 10
5	125 "	3 23
6	150 "	4 52
7	175 "	6 40
8	200 "	8 40
P.C.C.	215.4 ft.	10 00

432. SUPER-ELEVATION. On the curves the outside of the track should be higher than the inside, to neutralize the effect of centrifugal force. According to the principles of mechanics, the forre required to deflect a body from a rectiiinear path is $\frac{w v^2}{R g}$. in which w is the weight of the body, v the velocity in feet

per second, R the radius of curvature in feet, and g the acceleration due to gravity in feet per second. This force acts radially in the plane of the curve; and since the path of a body moving around the track is a curve whose plane is horizontal, the centrifugal force acts horizontally.

The horse is acted upon by two forces—gravity and centrifugal force. These forces and their resultant are shown in Fig. 80. If the track is level, the effect of the centrifugal force is the same as though the horse were traveling upon a surface inclined at an angle a with the horizontal; but if the outer edge of the track is elevated until the surface is perpendicular to the resultant represented by R in Fig. 80, page 290, the effect upon the horse is the same as though he were traveling upon a perfectly level track.

TABLE 32.

RECTANGULAR CO-ORDINATES FOR LOCATING THE SPIRAL FOR THE INSIDE EDGE OF THE HALF-MILE TRACK.

Point on Spiral.	Distance from the P.S. on the Tangent Prolonged.	Offset Perpendicular to the Tangent.
P.S.	00 ft.	0.0 ft.
1	25.0 "	0.06 "
2	50.0 "	0.47 "
3	75.0 "	1.60 "
4	99.9 "	3.78 "
5	124.6 "	7.39 "
6	149.0 "	12.70 "
7	172.9 "	20.11 "
8	195.9 "	29.83 "
P.C.C	209.4 "	37.06 "

From Fig. 80. it is readily seen that

$$\tan a = \frac{v^2}{Rg}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

Expressing v in terms of t, the number of minutes required to go a mile, and substituting for g its numerical value (32.16). equation (1) becomes

$$\tan a = \frac{241}{Rt^2}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

This formula shows the relation that should exist between the inclination of the track, and the number of minutes required to go 1 mile.

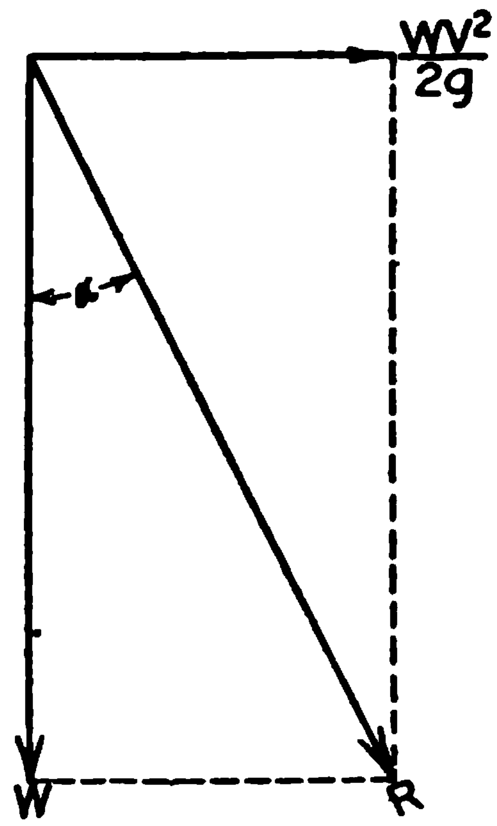


FIG. 80.

433. For the mile track shown in Fig. 78, page 286, and a 2-minute speed, *a* should be 0.15; that is, the inclination of the surface of the track on the circular curve should be 15 vertical in 100 horizontal. For the same track and a speed of a mile in 2 minutes and 40 seconds, the inclination should be 8 in 100, and for a mile in 3 minutes, 6.7 in 100. For the half-mile track shown in Fig. 79, page 288, the inclination on the circular curve should be practically twice that for the mile track above.

The super-elevation should gradually increase from nothing at the beginning of the transition spiral, i. e., at the end of the straight stretch, to the maximum at the beginning of the circular portion. The advantage of the transition spiral (§ 429) is that its radius of curvature decreases as the distance from the tangent point increases, and therefore the super-elevation at every point can be adjusted so as always to exactly neutralize the centrifugal force. When this condition is secured, the effect upon the horse will be the same as though he were traveling upon a level track all the time.

There is a little room for choice as to the speed for which the super-elevation shall be adjusted. If it is desired to build a track

upon which the fastest horses can make the fastest time, then the super-elevation should be computed for their fastest speed; but if it is desired to build a track upon which slower horses can make their fastest time, then the super-elevation should correspond to the fastest speed of the slower horses.

It seems to be the practice to give a slope of 1 in 13 (7.7 per 100) on the mile track shown in Fig. 70, page 279, and on the half-mile track shown in Fig. 73, page 282, 1 in 12 (8.5 per 100).

Horsemen claim that there is less need of super-elevation since the introduction of the low-wheeled sulky; but the claim is without foundation, as the proper inclination is independent of the height of the wheel of the racing sulky.

434. GRADES. It is desirable that the track should be level longitudinally; but this is not absolutely necessary. A number of celebrated tracks are not level. The Cleveland, Ohio, track, a very noted one, has an ascent of 16 inches in the first quarter and 24 in the second, and a descent of 30 inches in the third quarter and 10 inches in the fourth. Not a few horsemen believe that a slight grade is an advantage (see last paragraph of § 70). Frequently the introduction of a slight grade will materially decrease the cost of construction.

435. THE SURFACE. The surface should be formed of a soil that packs well and does not "cup," i. e., curl up when sprinkled. Clay, loam, gumbo, sandy loam, and muck are all good. If the natural soil is clear sand, it should be covered with a top dressing of clay or loam 3 to 4 inches deep, which is then thoroughly harrowed in.

436. Water is the first requisite to keep a track in good condition. If the track becomes too dry, it loses its elastic or "springy" condition, and becomes dusty; and therefore to keep it in proper condition, it should be sprinkled when dry. The sprinkler should deliver the water liberally and evenly in a fine spray.

The second requisite for proper maintenance is a good harrow. The proper time to harrow the track is after a rain or after sprinkling. If the track is dry, harrowing unduly pulverizes the soil, causing it to lose its cohesive properties and become "rotten" or "dead." and "cuppy." Too frequent or too deep harrowing produces substantially the same result. The harrow should have

many small sharp short teeth, so distributed that no two follow in the same line.

The implement of the next importance in the care of a race track is a leveler or "float." This consists of, say, five scantlings 2 inches by 4 inches by 16 feet set parallel to each other about 4 feet apart. On top of these are firmly spiked three planks 2 inches by 6 inches by 16 feet. The team is attached a little to one side of the center; and then as the frame is drawn over the track the clods are crushed, any slight depressions or gullies are filled, and any surplus loose earth and pebbles are worked to the outside of the track. It is important that the implement be large enough to cover considerable area, as otherwise it will follow the depressions of the surface, making them larger and deeper rather than filling them up; and it is also important that the outer end of the scraping edges may be unobstructed, so that any pebbles may be worked toward the outside of the track.

In the spring or after a severe storm which has washed considerable loose earth down to the inside of the curves, it may be necessary to go over the track with a scraping grader (§ 142) to work the surplus material back to the outside and fill up the gullies. The frequent use of the scraping grader is rendered unnecessary by the continuous use of the leveler described above.

437. Drainage. To secure good surface drainage, it is customary to give the surface on the straight stretches an inclination inward of 1 or 2 feet to 100 feet. This inclination is not enough to materially interfere with the traveling of the horses, and is of great advantage in keeping the track in good condition.

About 2 feet inside of the pole fence, there should be a ditch 1 foot deep and 2 feet wide; and from the inside edge of the track to the ditch there should be a slight inclination and an opportunity for an unimpeded flow of the water. From the bottom of the ditch should be frequent inlets to a tile which will carry all surface water speedily and entirely away.

PART II.
STREET PAVEMENTS.

439. Good pavements are necessary to the highest development of the commercial, sanitary and esthetic life of the city. The large proportion of people now dwelling in cities makes the subject of pavements an important one at present; and the fact that the urban population is increasing much more rapidly than the rural, and also the fact that the public is awakening to the necessity of ameliorating the condition of life in the city, will make pavements of increasing concern in the future.

440. The importance of pavements as an element in municipal finance seems not to be fully appreciated, and this subject has not received from municipal engineers and city officials the attention and study its importance merits. Whether measured by their influence upon the commercial, sanitary or esthetic life of the city, or by the amount of money invested in them, street pavements belong in the first rank of importance in municipal affairs.

Until quite recently no attempt has been made to collect statistics concerning Amerian pavements. Bulletin No. 24 (September 1900) of the U. S. Department of Labor contains statistics as to the number of square yards of pavements in each of the one hundred and twenty-nine cities having a population of 30,000 or over, but gives no data concerning the cost of these pavements. An approximate estimate of their cost may be arrived at by assuming an average price for such work. The total number of square yards of each of the principal kinds of pavements and their approximate cost is as follows:

Asphalt,—sheet and block	36 585 322	sq.	yd.	at	$2.75	=	$100 609 635
Brick	21 648 768	"	"	"	1.75	=	37 885 344
Cobble stone	21 600 245	"	"	"	0.80	=	17 280 196
Granite block	30 816 521	"	"	"	3.50	=	107 857 823
Gravel	38 645 022	"	"	"	0.20	=	7 729 004
Macadam	82 680 545	"	"	"	0.75	=	62 010 409
Wood block	27 727 572	"	"	"	1.25	=	34 659 465
Other kinds	9 553 000	"	"	"	2.50	=	23 882 500
	8 888 200	"	"	"	1.00	=	8 888 200
Total	278 145 195	"	"				$400 812 576

Under "other kinds" in the above table is included sandstone and limestone block, rubble, shell, tar distillate, granolithic, and perhaps telford—at least a number of cities separate macadam and telford pavements in their official reports. A number of cities have large areas of sandstone block, and from private investigations the author concludes that of the "other kinds" at least 9,553,000 square yards are sandstone block, and this has been entered separately in the above summary.

From the preceding table it appears that the pavements in these cities have cost $400,812,576; and as the total population is 19,036,845, the pavements have cost $21.06 per capita of their present population. The area of pavements per capita varies greatly in the different cities, being practically independent of the size and location of the city; and this average seems to agree fairly well with the area of pavements in a number of very much smaller cities investigated by the author. Therefore it will be assumed that the above average is representative of the entire country. According to the U. S. Census for 1900 there are 24,992,199 people dwelling in cities of 8,000 population or over. Therefore the investment in pavement in these cities amounts to $514,836,179. Measured by the money invested, street pavements are probably the most important of any single class of engineering construction except steam railroads.

441. According to Bulletin No. 100 of the 1890 census, the average annual expenditure for pavement construction and repairs in the cities of the United States having a population of 10,000 or over, was $1.72 per capita, being $1.54 in the cities having more than 100,000 population and $2.04 in cities from 10,000 to 100,000. If the same rate of expense obtained in 1900, the total annual expenditure for pavements in cities of 8,000 or more population was $43,000,000.

The first cost of pavement and also their annual cost is of such magnitude that merely as a financial question street pavements deserve the most careful attention and systematic study.

CHAPTER VIII.

PAVEMENT ECONOMICS.

442. Benefits of Pavements. The effect of pavements upon city life is so important and so far reaching that no enumeration is likely to include all of the benefits; but nevertheless it will be of advantage, particularly in discussing the proper distribution of their cost, to enumerate some of the more important of the benefits resulting from the construction of pavements. Briefly the principal advantages are:

1. Good pavements lessen the tractive power, and decrease the cost of transportation. See § 4–8 for a discussion of the cost of transportation.

2. They increase fire protection by facilitating the transportation of the fire engine.

3. They establish a permanent grade, which is an important matter when other improvements are to be made.

4. Pavements add to the appearance of the street by giving a uniform surface instead of the irregular one of an unpaved street.

5. They increase cleanliness, since the pavement is less dusty in a dry time and less muddy in a wet time than an unpaved street.

6. They increase healthfulness by removing holes filled with mud and filth.

7. Pavements permit pleasure driving at all seasons, and facilitate social intercourse.

8. Pavements allow the use of bicycles, which furnish cheap transportation and healthful recreation to many.

In discussions of this subject it is customary to include the enhanced value of the property as one of the advantages of a pavement; but the increase in the value of the property is simply a

measure of the benefits enumerated above, and hence should not be again included.*

The first three benefits above may be regarded as financial advantages and the last four as sanitary and esthetic. It is impossible to compute even approximately the financial, much less the sanitary and esthetic value of good pavements; but it is safe to say that they are an absolute necessity to both the business and resident districts of the larger cities and also for business districts of the smaller cities, and that on residence streets of small cities good pavements add greatly to the health, comfort and pleasure of life.

443. Apportionment of the Cost. There is much discussion as to who in equity should bear the cost of the pavement. There are three distinct views. 1. A few claim that as they own neither a horse nor a vehicle and do not use the pavement, they should not be required to pay for it. Although a resident may not travel upon the pavement, it is used by those who serve him; and a pavement confers other benefits besides those relating to transportation. It is entirely impracticable to distribute the expense according to the use made of the pavement. 2. Others claim that the pavement is for the benefit of the general public of the city at large, and hence the abutting property should pay no more than that in other parts of the city. This claim ignores the fact that the abutting property secures a distinct benefit for which it should be required to pay. Laying at least part of the cost upon the property tends to discourage a demand for lavish expenditures for unnecessary improvements, that possibly might be insisted upon if the city contributed the entire cost. 3. Many hold that the benefits accrue only to the abutting property, and that therefore the owner of the abutting property should bear the entire cost. This claim disregards the fact that the pavement is for the use of the general public, and benefits all the people and all those having business interests in the city. An improvement in any part of the city is an indirect benefit to the city as a whole. In excuse of this method of payment, it is sometimes claimed that,

* For an interesting study of the effect of pavements in increasing the value of abutting property, see *Engineering Record*, Vol. 25, p. 418–19.

although the pavement confers a general benefit, the inequality will be compensated when all the streets are paved. The answer is that all the streets may never be paved, and besides traffic naturally concentrates on certain lines and nearly ignores certain others, and therefore some pavements will require much more care and expense than others. Further, there should be no objection to letting every property holder pay a part of his ultimate share as the work progresses, instead of paying it in a lump sum when the street in front of his own property is paved. The second or third view or a combination of them usually obtains. Table 33, page 298, shows the method of apportioning the expense in fifty American cities.*

The practice is slightly different for the grading, the original paving, and the re-paving. The cost of grading in 54 per cent of these cities is all paid by the abutting property, in 32 per cent all by the city, and in 14 per cent part by each in varying proportions. The cost of the original paving in 62 per cent of the cities is charged entirely to the private owner, in 22 per cent entirely to the city, and in 16 per cent it is divided between the two. The cost of re-paving in 42 per cent of the cities is paid wholly by the property, in 40 per cent wholly from the general tax, and in 18 per cent it is divided between the two. In some cities a street in an addition or subdivision is not accepted by the municipal authorities until it has been graded, and hence it is done at the expense of the abutting property; but on the other hand, some cities are willing to bear a part of the cost of the street improvement, and therefore pay for the grading. Only one quarter of the above cities pay the major part of the cost of the original paving, while 40 per cent pay the major part of the cost of re-paving. It is the custom, where there is a car track on the street, to require the railroad to pave an 8-foot strip for each track, the remainder being divided between the abutting property and the city at large in the same proportion as on the streets where there is no track. In some cities intersecting streets are regarded as municipal property, and the cost of paving the intersection is assessed against the street, i. e., against the city; but in others the cost of paving the street inter-

* From an article on Theory and Practice of Special Assessments by J. L. VanOrnum, in Trans. Amer. Soc. of Civil Engineers, Vol. 38, p. 336–422.

TABLE 33.

Apportionment of Cost of Pavements in Fifty Cities.

Ref. No.	Locality.		Grading. Per Cent Paid by		Original Paving. Per Cent Paid by		Re-paving. Per Cent Paid by	
	State.	City.	Property.	City.	Property.	City.	Property.	City.
1	Alabama	Montgomery	50	50	50	50	50	50
2	Arkansas	Little Rock	100	......	100	......	100	......
3	California	San Francisco	100	......	100	......	......	100
4	Connecticut	Hartford	......	100	67	33	......	100
5		New Haven	......	100	*a*	......	*b*	......
6	Dist. of Columbia	Washington	......	100	......	100	......	100
7	Delaware	Wilmington	......	100	......	100	......	100
8	Florida	Jacksonville	50	50	50	50	50	50
9	Georgia	Atlanta	......	100	67	·33	67	33
10		Augusta	50	50	50	50	50	50
11	Illinois	Peoria	100	......	100	......	100	......
12	Indiana	Indianapolis	100	*d*	100	*d*	100	*d*
13	Iowa	Burlington	......	100	100	*c*	......	100
14	Kansas	Topeka	......	100	100	......	100	......
15	Kentucky	Louisville	100	......	100	......	......	100
16	Louisiana	New Orleans	75	25	75	25	75	25
17	Maine	Portland	......	100	......	100	......	100
18	Maryland	Baltimore	100	......	100	......	......	100
19	Massachusetts	Lowell	100	......	......	100	......	100
20		Springfield	......	100	......	100	......	100
21		Worcester	100	......	......	100	......	100
22	Michigan	Detroit	100	*c*	100	*c*	100	*c*
23	Minnesota	Minneapolis	......	100	100	*c*	100	*c*
24		St. Paul	100	......	100	......	100	......
25	Missouri	Kansas City	100	......	100	......	100	......
26		St. Louis	......	100	100	......	100	......
27	Nebraska	Omaha	50	50	100	*c*	100	*c*
28	New Hampshire	Manchester	......	100	......	100	......	100
29	New Jersey	Newark	100	......	100	......	100	......
30		Paterson	100	......	100	......	......	100
31	New York	Albany	100	*d*	100	*d*	100	*d*
32		Brooklyn	100	......	100	......	50	50
33		Buffalo	100	......	100	......	100	......
34		New York	100	......	100	......	......	100
35		Rochester	100	......	100	......	100	......
36		Syracuse	100	......	100	......	100	......
37	Ohio	Cincinnati	98	2*c*	98	2*c*	98	2*c*
38		Dayton	100	*c*	100	*c*	100	*c*
39	Oregon	Portland	100	......	100	......	100	......
40	Pennsylvania	Harrisburg	100	......	100	......	100	......
41		Philadelphia	......	100	100	......	......	100
42		Scranton	100	......	100	......	50	50
43	Rhode Island	Providence	100	......	......	100	......	100
44	South Carolina	Charleston	......	100	......	100	......	100
45	South Dakota	Sioux Falls	100	*c*	100	*c*	100	*c*
46	Tennessee	Nashville	......	100	......	100	......	100
47	Utah	Salt Lake	50	50*c*	100	*c*	100	*c*
48	Virginia	Richmond	......	100	......	100	......	100
49	Washington	Seattle	100	......	100	......	100	......
50	Wisconsin	Milwaukee	100	*c*	100	*c*	......	100

a. 1 sq. yd. for each front foot; city remainder.
b. 3½ sq. ft. " " " " ; " "
c. City pays for street intersections.
d. City does not pay for street intersections.

sections is included in the charge against the abutting property. In most cities lots owned by the municipality pay the same proportion of the cost of the street improvements as private property, although usually special authority is required thus to assess municipal property.

Table 33 also shows that as a rule the eastern and southern cities pay a larger proportion of the cost of pavements than do the western. This difference in practice is probably due chiefly to the limited revenues of new cities and to the many demands upon the general tax for the numerous and varied necessities of rapid growing municipalities; consequently the cost of pavements, improvements having a definite local benefit, have been charged to the abutting property. It is equitable and just that the cost should be borne jointly by the private property and the city at large, since then the cost falls upon both interests which directly profit by the improvement, and neither receive a substantial benefit without sharing in its cost.

Ordinarily the proportion of the expense to be borne by the municipality and by the private property is determined wholly by financial considerations or usage, and is made uniform over the entire city; while equity and justice demand that a distinction should be made depending upon the character of the traffic. The interests of the general public in a street vary greatly between a residence street, a business street, and a general thoroughfare. To pave the first the public should pay only a small share, say, 20 or 30 per cent; for the second, say, 40 or 50 per cent; and for the third 60 or 75 per cent. Some such variation in the proportion to be borne by the two interests finds further justification in the fact that if the street becomes a general thoroughfare, some of the benefits enumerated in § 442 as accruing to the abutting property may be nullified by the noise and dirt.

444. SPECIAL ASSESSMENTS.* The proportion of the cost of a pavement paid by the private property is usually collected as a special assessment, which has been defined as "a compulsory

*For an interesting and instructive discussion of the history and theory of special assessments, see Special Assessments by Victor Rosewater—Vol. 2, No. 3 of Studies in History, Economics and Public Law. 152 p., 6 × 9 inches, Columbia College, New York, 1893. See also the article referred to in the foot note on page 297.

contribution paid once and for all to defray the cost of a special improvement to property, undertaken in the public interest, and levied by the government in proportion to the special benefits accruing to the property owner." Special assessments differ from taxes, both general and special, in that the former are based upon a direct and measurable benefit conferred upon the contributor, which is the measure of his liability to be taxed; while taxes are levied for the maintenance of the institutions and interests of the government, without reference to the particular benefits conferred, according to the ability of the contributor to pay. The construction of pavements to be paid for by special assessment must be done under the direction of the public officials.

In a general way it may be said that there are two distinct methods of apportioning the amount to be paid by the private property; viz.: (1) according to the frontage, and (2) according to the area.

445. Frontage Rule. By far the more common method of apportioning the assessments is pro rata according to the frontage upon the improvement. This method is often designated as the front-foot rule. Of the forty-five cities in Table 33, page 298, which assess the private property for street improvements, thirty-eight or 84 per cent follow the frontage rule, three use a combination of frontage and area, one uses area alone, one value alone, and in two of the cities the method employed is left to the judgment of the assessing board.

Ordinarily the frontage is an equitable basis upon which to distribute the cost; but under some circumstances a rigid apportionment according to frontage gives anomalous results. For example, if most of the lots have their shorter side on the improvement and one has its longer side thus placed, the frontage rule will give inequality—particularly if the latter lot is very narrow. This condition frequently occurs—for example where the most of the lots front upon the street to be paved, while some front upon an intersecting street. In this case, it is customary to extend the assessment to the middle of the block; that is, assess the lots between the pavement and the center of the block, in which case it becomes a difficult matter to determine the equitable portion for each of these lots. A rigid adherence to the frontage rule

sometimes works injustice near the intersection of two streets cutting each other at an acute angle. However, no method can be devised that may not require modification to fit unusual conditions.

446. Area Rule. In a few cities, 7 per cent of those in Table 33, page 298, the cost of street improvement is distributed in proportion to the area of the abutting lots; but usually the area is used in combination with the frontage. Thus in Brooklyn, N. Y., 60 per cent of the cost is distributed in proportion to the frontage and 40 per cent according to the area. An amendment to the charter of St. Louis proposes to charge 25 per cent of the cost of the pavement according to the frontage and 75 per cent according to the area. The area rule finds its greatest justification on curved streets.

447. Corner lots are usually the cause of irritation and objection under either the frontage or the area rule, and the method of assessing them differs materially in different cities. In some cases each margin is considered a front on its proper street, without any modification in the rate of assessment; in a few cases under the area rule an additional per cent is imposed upon the corner lot for the pavement of either street; but usually the corner is assessed according to frontage at a less pro rata than the inside lots, since it may be assessed on both streets.*

448. Terms of Payment. There are various methods of paying the assessment. 1. The entire amount may become a lien upon the property as soon as the work is completed, to be collected (*a*) by the contractor, or (*b*) by the city acting only as collecting agent for the contractor, or (*c*) by the city, which also becomes responsible to the contractor for the payment of the money. 2. The amount may be divided into equal annual installments, usually five or ten, with interest on deferred payments, to be collected (*a*) by the contractor, or (*b*) by the city, the contractor receiving special paying-district bonds, or (*c*) by the city, the contractor receiving general city-bonds. 3. The city may raise a paving fund by general tax or by selling bonds, and pay for improvements as made, independent of the collection of the special assess-

* For a summary of judicial decisions on this and similar matters, see Trans. Amer. Soc. of Civil Engineers, Vol. 38, p. 381, § 20.

ments. The second method is the more common. The first is objectionable because the amount becomes immediately due; and the third is objectionable on account of the difficulty of making the assessments and collections keep pace with each other, and also because of a tendency to produce extravagance.

449. Legality of Levy. Special assessments can be levied only under explicit authority of the law. The different states have very complete and explicit statutes governing special assessments; and the courts always hold that any material departure from the prescribed procedure invalidates the assessment.

450. GUARANTEEING PAVEMENTS. It is a common custom to require the contractor to guarantee the pavement for a term of years, which guarantee is supported either by an indemnifying bond or by a portion of the cost of the pavement retained by the municipality until the expiration of the specified period. In some cases the guarantee is an agreement that if time shall reveal that the materials or the method of construction are not according to the contract, the contractor shall make the defect good; but in other cases, the so-called guarantee is virtually a contract to maintain the pavement for the specified period and to turn it over in good condition at the end of that time.

Apparently the guarantee originated in this country with the introduction of sheet asphalt pavements. The material was new, the method of laying it was untried, and hence no city would run the risk of paying for an unknown and uncertain pavement; consequently the contractor agreed to guarantee the pavement for a period of years. At present most cities continue to exact a guarantee for asphalt pavement, ranging from five to fifteen years, on the ground that the method of testing the material and the manner of laying it are too little understood by engineers to insure good and durable work without a guarantee. At the beginning of the use of brick as a paving material a guarantee was sometimes demanded; but at present it is as a rule not required with this material.

451. The requirement of a guarantee of the pavement is justifiable when the material to be used is new and there is little or no opportunity for the engineering department to acquire the knowledge necessary for an effective inspection of the work; but as a

rule a guarantee, particularly for a long time, is unwise for the following reasons: 1. The contractor has no control over the street after the pavement is completed; and it is difficult to discriminate between defects due to improper material and the effects of ordinary wear, which may differ materially on different streets. It is also difficult to discriminate between defective workmanship and damages due to causes for which the contractor is in nowise responsible, as, for example, fires, escape of illuminatng gas, settlement of trenches made after the completion of the pavement, etc. 2. It is difficult to enforce the guarantee clause if, on the one hand, the engineering department inspects the material and accepts the workmanship; and, on the other hand, if a representative of the city does not inspect the work there is liability that the streets may be needlessly obstructed and the public greatly inconvenienced by a bungling experiment by the contractor. The difficulty of enforcing a guarantee is much less in a large city where there is more work to be had and where the contractor desires to protect his reputation with a view to securing contracts in the future, than in a small city having but little work; and the difficulty is still further increased if the law requires that the contract shall be let to the lowest responsible bidder—as is usually the case.

The contractor objects to the guarantee, not without justice, on the following grounds: 1. The specifications are prepared by the engineering department of the city, and as the quality of the material and the method of construction is prescribed by the city and subject to the approval of its representatives, the contractor should not be held responsible for the result. However, the sufficient answer to this objection is that the contractor accepts the specifications when he enters into contract, and is therefore rightfully bound by them. 2. The expense is needless and excessive, whether an indemnifying bond is required or a per cent of the contract price is retained, which expense in the long run adds to the cost of the pavement. It is more expensive to the contractor if the city retains a per cent of the contract price, since a portion of his capital is then tied up, which in turn drives out the small contractor, decreases competition, and tends to increase the cost of the pavement. On the other hand, the interests paying for the

pavement are better protected if the city retains a per cent than if an indemnifying bond is accepted, since in the former case the city has the money in hand with which to make the needed repairs in case the contractor fails to do so; but the proper care of such deferred pavements adds materially to the labor and responsibility of municipal administration.

The contributing property holders and citizens favor the guarantee as a defense against incompetent or dishonest city officials and employees. The guarantee is also sometimes defended on the ground that it is the cheapest method of securing good work, since it is impossible at reasonable cost for the engineering department to inspect all stages of the preparation of the material or to acquire the knowledge necessary for an effective supervision of the construction; but in general this claim is not true. It is neither creditable to the engineering profession nor economical to the municipalities to leave all exact knowledge of paving matters in the hands of the paving contractors.

452. The proper length of the guarantee period is a matter about which there is considerable difference of opinion. For asphalt pavement a guarantee for five years is quite common, although sometimes a fifteen-year guarantee is required. With stone block, brick and most other forms of pavements nine months, or at most a year, is sufficient to reveal any serious defect of material or workmanship, and therefore a long guarantee is not necessary.

453. Maintenance by Contract. As stated above it is common to require a so-called guarantee which is virtually a contract for maintenance for the specified period. Maintenance by contract is justifiable if the engineering department of the city does not possess, or can not reasonably be expected to obtain, the information necessary in repairing the pavement; but as a rule maintenance by contract is undesirable, for two reasons: 1. The contractor has no control over the streets, and the repairs required are dependent upon the restrictions against opening the pavements and also upon the regulations for keeping the streets clean. 2. It is difficult to specify beforehand the amount and the nature of the repairs that may be required by the ordinary use of the pavements, particularly as the opening of new streets or the paving of others

may materially alter the amount or nature of the traffic on any particular pavement. 3. It is impossible to determine accurately the condition of the pavement at the end of the contract period. 4. With a new and untried material it is impossible to determine what is a reasonable expense for maintenance.

A contract for maintenance is sometimes defended by the property holders on the ground that thereby some one is secured who is admittedly responsible for the condition of the pavement and who is more amenable for neglect than are city officials. However, if the city officials can not be trusted to repair the pavements directly, it is doubtful whether they may reasonably be expected to supervise the repairs to be made by the contractor. The choice between maintenance by contract and by municipal authorities directly will usually depend upon the local conditions.

The pavements of Paris, France, were formerly maintained by contract; but are now maintained by the city directly.

454. Tearing up Pavements. The most serious cause of the destruction of pavements is the frequency with which they are torn up for the introduction or repair of underground pipes, conduits, etc. No pavement has been introduced, and probably none ever will be, which is not seriously injured by being torn up. The only remedy for the frequent disturbance of pavements is the construction of a subway in which to place pipes, wires, etc.; but it is doubtful if any such remedy would be lasting, for the streets are continually being put to new uses. Formerly it was thought sufficient to provide for water and gas pipes and sewers; while now conduits are required for telegraph, telephone, and electric light wires, and street-car tracks are constructed on the surface, above the surface, and below the surface, and in some cities space is required for pneumatic tubes, and pipes for distributing heat, compressed air, cold and hot water, etc.

The only thing that can be done is to reduce the opening of the pavements absolutely to a minimum, and then to take the utmost care to see that as little damage as possible is done in making the opening and that the pavement is restored in the best way possible. It is stated that in 1896 in New York City a quarter of a mile of trench was opened for each mile of pavement, and in addition there was an opening for each 35 linear feet of street. The year

stated was about an average for those immediately before and after.

The amount of money spent in digging up the streets is a considerable item, not counting the interference with travel and business; but the expense, being distributed among various interests, is not usually sufficient to cause any one company to re-construct its system. It is probable that the interests of the public are frequently sacrificed to the interests of the private companies using the streets—usually without paying for the privilege.

Under the best municipal administrations of Europe neither corporations nor individuals are permitted to disturb the pavements. All removals and restorations are done by the city's own employees, upon the deposit, by the parties who require the streets to be opened, of a sufficient sum to cover the expense of each piece of paving done, at a fixed price per yard according to the kind of pavement. Moreover, interference with the pavements is of rare occurrence, for the companies having pipes underground are required thoroughly to examine and reinstate their mains and services concurrently with the paving of a street, due notice of the execution of which is given by the city.

CHAPTER IX.

STREET DESIGN.

456. From the point of view of future needs—commercial, sanitary, and esthetic,—it is unfortunate that cities grow up by successive additions under the stimulus of private greed and real estate speculation, without any comprehensive or well considered street plan. In some instances—notably Paris, London, and Boston,—vast sums have been spent to correct what might have been prevented in the original plan of the streets.* In most cities transformation—slow and expensive, if it come at all—is the only remedy; but a mended article is never as good as one well made at first.

Unfortunately there are few cities in this country having adequate regulations governing suburban development. Municipal authorities should regulate the street plan of subdivisions and additions so as to secure a harmonious whole, and particularly with a view of making the streets continuous and to afford suitable channels of communication. Where such regulations do not exist, streets will be laid out in such a way as best to develop the particular property, regardless of the interests of the public. Washington City, which has the best street plan of any American city, has been disfigured by ill planned additions; although at present stringent rules govern the width and the arrangement of the streets of additions and subdivisions.

457. STREET PLAN. Since an engineer is occasionally called upon to plan a city, and often to lay out additions to cities and villages, the various street plans for the city will be considered. In plan-

* For example, Paris spent $14,000,000 in improving the Rue de Rivoli, and London $33,000,000 on the Strand Improvement.

ning the streets of a city three objects should be kept in mind; viz.: (1) the subdivision of the area in such a manner as to give the maximum efficiency for business or residence purposes; (2) sufficient accommodation for the pedestrian and vehicular travel on the streets; and (3) good drainage and easy communication between the different parts of the city.

458. Size of Lots. Owners in subdividing property are anxious to make as many lots as possible; and in some other respects small lots are to be preferred. It is desirable to make the lots of such a size that few of them will be subdivided, as clearness of identity is maintained by always referring to the original number in transferring or assessing the lot. A frontage of 25 feet seems the best. This width is suitable for business purposes, and for residence streets two or more lots will give proper grounds. Business lots are sometimes made only 18 or 20 feet wide, but 25 feet is by far the more common.

Lots are seldom less than 100, nor more than 180, feet deep; and usually vary from 100 to 150 feet. A lot more than 150 feet deep is objectionable, because of the temptation to build unsightly residences fronting on the alley and because of the difficulty of keeping a deep lot in good sanitary condition.

459. Size of Blocks. With a rectangular system of streets, the blocks are preferably long and narrow; since the distance required between streets in one direction is only that necessary to give the proper depth of lots, while in the other direction the streets need be only close enough to provide convenient channels for the traffic.

For convenience, especially in business districts, it is best to have an alley run lengthwise through the block. The alley varies from 10 to 30 feet, but is usually from 16 to 20 feet.

The above depth of lot and width of alley makes the width of the block 220 to 330 feet. The length of the block will depend upon the requirements for traffic perpendicular to the principal streets. Sizes of blocks vary much in any particular city, and still more between different cities. The following are the dimensions of typical blocks in several cities: Boston, 220 × 400 ft., and 100 × 550 ft.; New York, 200 × 900 ft., and 200 × 400 ft.; Philadelphia, 400 × 500 ft., and 500 × 800 ft.; Washington, 400 × 600

ft., and 300 × 800 ft.; Montreal, 250 × 750 ft.; Chicago, 300 × 350 ft., and 300 × 500 ft.

Fig. 81 is given to illustrate the advantages to be derived from a careful study of the best size of blocks and of the most advantageous arrangement of streets. The left-hand side of the diagram shows the typical arrangement of streets and blocks in the residence district of New York City, the shaded portions repre-

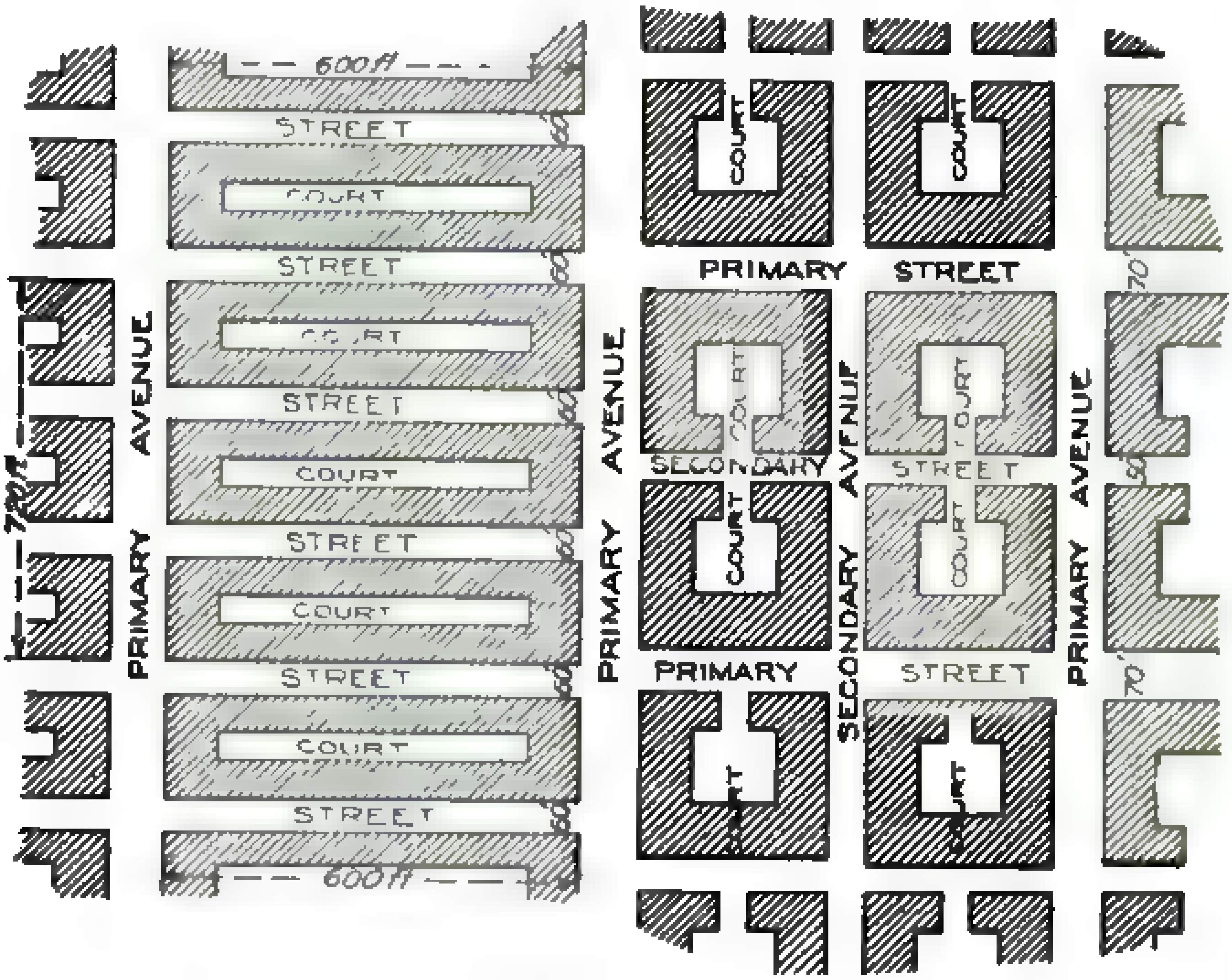


Fig. 81.—Improved Arrangement of Streets and Blocks.

senting the usual buildings. The right-hand side shows a much superior arrangement.* The three center blocks of the present plan comprise an area of 720 × 800 feet, and contain 480,000 sq. ft. of building area and 96,000 sq. ft. of streets, and in the corresponding area of the proposed plan, there are 481.000 sq. ft. of building area and 94.200 sq. ft. of streets; therefore the two plans

* Proposed by Mr. J. F. Harder, in Municipal Affairs, Vol. 2, p. 41–44. Reform Club, New York City, 1898.

give substantially the same area for buildings and for streets. In the first case the length of streets is 1,600 feet, in the second 1,520 feet; therefore the two plans have practically equal light and air. The proposed arrangement is the better in the following particulars: 1, number of corner sites; 2, accessibility of rear entrances for delivery of provisions, coal, etc., and the removal of garbage, ashes, etc., and in case of fire; 3, removal from the street of dangerous and cramped cellar entrances; 4, removal from the main or primary streets of the loading and unloading of trucks; and 5, increased transportation facilities in a direction perpendicular to the length of the original blocks.

460. Location of Streets. In planning a system of streets there are two objects that should be carefully considered; viz.: the drainage and easy communication between the different sections of the city. Not infrequently these elements have been overlooked or neglected. The surface drainage, the sewerage and the traffic must follow the general slope of the land; and therefore if there is much irregularity of contour in the site, a location of the streets with reference to the contours will afford at once the best drainiage and the easiest communication between different parts of the city. If the site is nearly level, the relationship between the slope of the land and the direction of the streets is comparatively unimportant; but the arrangement of the street plan to afford the greatest facilities for communication between the different parts of the city is still an important matter. Therefore the conclusion is that on a site of irregular contour the streets should be located with reference chiefly to the topography, and on a level site primarily to secure the most direct and easiest intercommunication.

461 *Location with Reference to Topography.* Unfortunately in this country our very desirable rectangular system of public land survey has frequently led to the adoption of a very undesirable rectangular system of streets which, though convenient for dividing property into the greatest number of rectangular lots upon which can be built the greatest number of rectangular buildings, has little else to recommend it. Surface drainage, sewerage and traffic should follow the slope of the country, and any attempt to deviate from this becomes a serious question in the building of a city upon

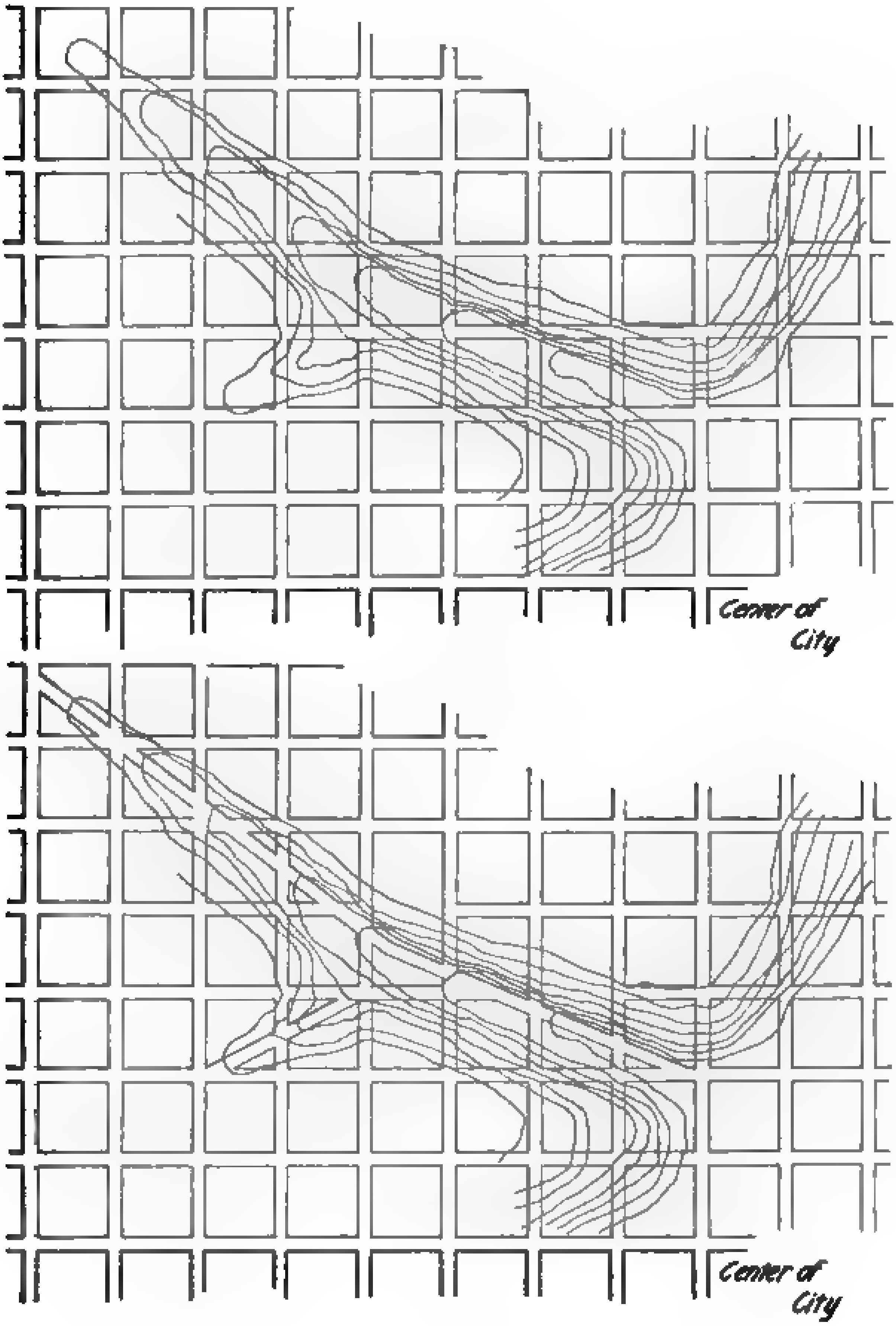


Fig. 82.—Location of Streets with Reference to Contours

any but nearly level ground. The streets are of necessity the drainage lines of the city and should be placed in the natural valleys, and the failure so to locate the streets in many cities where the land is very irregular in contour has led to great expense in the construction of the streets and of a system of storm-water sewers.

The upper half of Fig. 82, page 311, shows an actual case of a system of rectangular streets located without any reference to the topography of the site; and the lower half of the same diagram shows a proposed arrangement * that would save much expense in grading the streets and at the same time give a quick entrance into the center of the city, and also give long easy grades from the heart of the city to the higher outlying district.

462. *Location with Reference to Directness of Communication.* There are three distinct general plans for city streets with reference to directness and ease of communication.

463. One consists of a system of parallel streets crossing a similar system at right angles. This is often called the checker-board system, but more properly the rectangular system, since the blocks are not necessarily squares. This arrangements gives the maximum area for blocks, and also furnishes blocks of the best form for subdivision into lots. The rectangular system is the most common, and has its most marked exemplification in Philadelphia.

464. A second arrangement of streets consists of the rectangular system with occasional diagonal streets along the lines of maximum travel. This system was employed by L'Enfant in planning the city of Washington. Fig. 83 shows a portion of that city. To a limited degree, the same plan was adopted in laying out the city of Indianapolis, which has four broad diagonal avenues converging to a circular park in the center. These two are the only cities of any importance in which this system was adopted in advance of building. This system is usually, but somewhat improperly, called the diagonal system.

The chief advantage of the diagonal street is the economy due to the saving of distance by traversing the hypothenuse instead of the two sides of a right triangle. In Rome, London, Paris, and in numerous other smaller places in Europe, whole districts have

* By W. D. Elder in Proc. Michigan Engineering Society, 1898, p. 52.

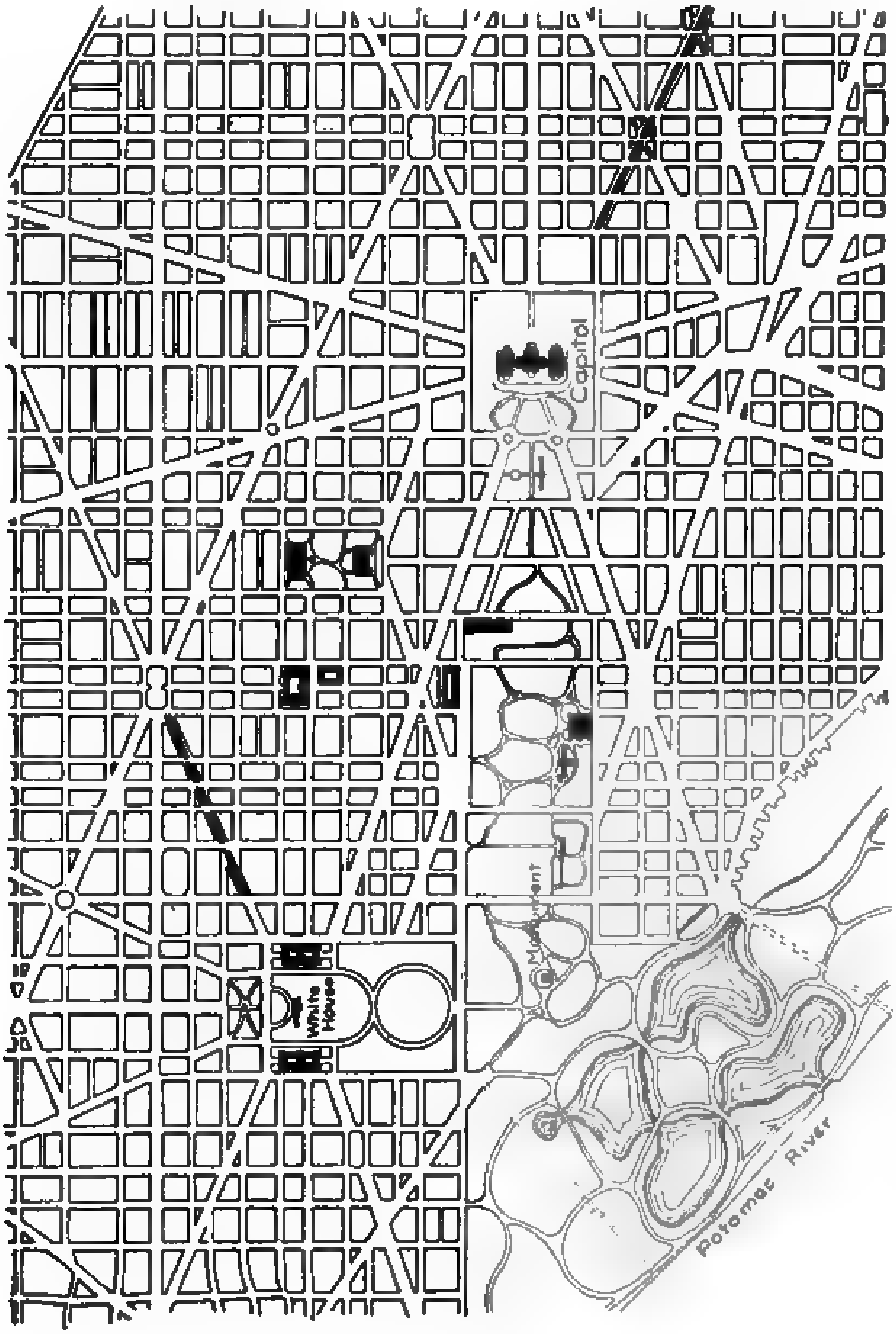


FIG. 83.—STREET PLAN OF WASHINGTON, D C

been razed to make way for new streets to serve as arteries for increased traffic.

A second, and by no means an unimportant, advantage of the combination of the diagonal and the rectangular system is the open squares and spaces so grateful to the eye and of no little sanitary value in compactly built cities. New York City has recently been spending a million dollars a year to create such spaces by purchasing the land and demolishing the buildings.

Although the diagonal avenue occupies ground that might otherwise be used for building purposes, there is a compensating advantage in the greater length of street front obtained.* In many cases the total cost of cutting diagonal streets through built-up districts has been paid by the increased value of the property on and near the street thus opened up.

465. The third arrangement of city streets is the ring or concentric plan, which is very popular in Europe. The most noted example is Vienna with its Ring-strasse (ring street) within and its Gürtel-strasse (girdle street) without. The former is 187 feet wide and encircles the public buildings and the leading houses of business and amusement. The enclosed network of streets intersect the Ring-strasse at forty points, and outward from it extend fifteen main radial avenues.

466. WIDTH OF STREETS. The width of city streets is important on account of its influence upon the ease with which traffic may be conducted and also because of its effect upon the health and comfort of the people by determining the amount of light and air which may penetrate into thickly built-up districts. The streets of nearly all large cities are too narrow, being crowded and dark. A more liberal policy in planning streets would probably be of pecuniary advantage, since there is usually an enhanced financial value due to wide streets. A lot 100 feet deep on a street 80 feet wide is usually more valuable than a lot 110 feet deep on a street 60 feet wide; that is to say, within reasonable limits land is usually more valuable in the street than on the rear of the lot. Wide streets are especially needed where they are bordered by high buildings or are to carry street railway lines.

* For a discussion of this phase of the subject, see an article by L. M. Haupt in Jour. Franklin Inst., Vol. 103, p. 252.

In order properly to accommodate the traffic in business districts of cities of considerable size, a street should have a width of 100 to 140 feet, the whole of it being used for roadway and sidewalks; while residence streets in a city of considerable size, where the houses are set out to the property line and stand close together, should have a width of 60 to 80 feet. Although it is advantageous to have a wide street, it is not necessary, nor even desirable, that the whole width be paved; the central portion may be paved, a strip on either side being reserved for grass plats. The width of the pavement should be adjusted to the amount of traffic, which varies greatly accordingly as the street is a business street, a thoroughfare, or an unfrequented residence street.

The width of the streets in different cities varies greatly. In the older places in New England and the Central States, many of the streets are only 30 to 40 feet wide; but in the West a street is seldom less than 60 to 66 feet wide. In both regions the principal streets are often 80 to 100 feet wide, and in many of the larger cities the boulevards and great avenues are 150 to 180 feet. The main avenues in Washington are 160 feet wide, in New York 135, and in Boston 180 feet.

At present the regulations governing the width and the arrangements of additions and subdivisions of Washington, a city which has the best street plan of any in America (see § 464), are: "No new street can be located less than 90 feet in width, and the leading avenues must be at least 120 feet wide. Intermediate streets 60 feet wide, called places, are allowed within blocks; but full-width streets must be located not more than 600 feet apart."

467. Area of Streets. The proportion of the area of the city devoted to streets varies greatly, particularly between the older and the newer cities. The following is the per cent of street area in a few extreme cases of American cities: *

Minimum Street Area.		Maximum Street Area.	
1. Taunton, Mass.	3.20 per cent	Duluth, Minn.	86.7 per cent
2. Worcester, Mass.	5.43 " "	Dallas, Tex.	78.3 " "
3. Binghamton, N. Y.	7.55 " "	Denver, Colo.	73.9 " "
4. Philadelphia, Pa.	8.42 " "	Indianapolis, Ind.	56.4 " "
5. Boston, Mass	8.76 " "	Washington, D. C.	43.5 " "
6. Lowell, Mass	8.92 " "	Davenport, Ia.	42.1 " "
7. Fall River, Mass.	9.17 " "	Evansville, Ind.	40.8 " "

* Census Bulletin No. 100—July 22, 1891,—p. 16.

The area devoted to streets and alleys in a few of the principal cities of the world is as follows:

AREA OF STREETS AND ALLEYS.

1.	Washington	54 per cent
2.	Vienna	35 " "
3.	New York City	35 " "
4.	Philadelphia	29 " "
5.	Boston	26 " "
6.	Berlin	26 " "
7.	Paris	25 " "

468. WIDTH OF PAVEMENT. It is wise to make the streets of residence districts of liberal width for sanitary and æsthetic reasons; and also because the future of the street can not be certainly foreseen,—the residence street may become a business street, or an unfrequented street a thoroughfare. However, it is not necessary that the whole width should be devoted to wheelways and sidewalks, particularly in small cities. A grass plat between the sidewalk and the pavement, in which shade trees are set (§ 491), adds to the beauty of the street and to the comfort of the residents by removing the houses farther from the noise and dust of the pavement. The grass plat or parking also affords an excellent place in which to place water and gas pipes, telephone and electric-light conduits, etc. In large cities where the street front is built up solid with houses of several stories, it may be necessary to dispense with the grass plat, and to devote the entire street to sidewalks and roadway.

It is universally admitted that pavements are desirable; but often, owing to the unwillingness of at least some of the people to pay for them, it is difficult to secure them. Except for the cost, the wider the pavement the better; but length is more valuable than width. An excessive width is a needless expense, and delays or prevents the getting of any pavement at all; hence one help toward securing pavements is to make the pavement only wide enough to accommodate the traffic. Not infrequently the pavements of suburban and residence streets are needlessly wide. A narrow pavement not only costs less to construct, but also costs less to clean and sprinkle; while the cost of maintenance depends chiefly (or, with a pavement not subject to natural decay, wholly) upon the amount of traffic, and hence is nearly (or entirely) independent of the width.

469. Without Car Track. A width of 18 feet affords sufficient room for a vehicle to pass when another is standing on each side of the pavement—a rare occurrence;—and therefore it appears that a pavement 18 feet wide is sufficient for the less frequented residence streets. The only objection to a very narrow pavement is the difficulty of turning a team in such a street. The seriousness of this objection depends upon the construction of the vehicle. Many delivery wagons, express wagons, etc., may be turned on an 18-foot pavement. If occasionally a vehicle is compelled to go to the corner to turn, or even to drive around the block, the inconvenience is not very serious, and is so infrequent as not to justify any considerable expense to prevent it. A width of 20 to 24 feet is probably sufficient for a majority of residence and suburban streets. When a residence street is an artery of travel, it may be necessary to make the pavement wider than stated above. In a number of cities, there has been a marked tendency in recent years to reduce the width of pavements on residence streets.

Thirty feet affords sufficient room for two vehicles to pass each other where two others are standing at the curb; and therefore this width of pavement is ample for business streets in small places. On a narrow business street it may be necessary to curtail the width of the pavement to prevent the sidewalk space from being unduly encroached upon.

In many of the cities the width of the pavement is uniformly a fractional part of the total width of the street, regardless of the needs of traffic. In many cities, both American and European, the pavement is three fifths or 60 per cent of the width of the street. In New York City and Brooklyn the rule seems to be to make the pavement half the width of the street. In Washington City there is no hard-and-fast rule, but the following is the usual relation: on streets 60 feet wide or less, the pavement is 25 feet or 40 per cent of the width of the street; on streets from 60 to 90 feet wide, the pavement is 25 to 35 feet, or 40 per cent; and for streets 130 to 160 feet wide, the pavement is 40 to 50 feet, or 30 per cent.

470. With Car Track. For a residence street containing a car track, the minimum width permissible is 28 feet, which will allow a car to pass with a vehicle on each side of the track. In Brook-

lyn a great many streets only 34 feet wide between curbs contain a double line of street-car tracks, which leaves a space of only 9½ feet between the track and the curb. This is astonishingly small, but seems to do fairly well.

On a business street containing a car track, it is wise to make the pavement wide enough to permit a vehicle to pass between the car while another vehicle stands at the curb. This will require about 48 feet. If the street is too narrow to permit this width of pavement and also the proper width of sidewalks, only one track should be allowed in the street; if a double track is necessary, the cars should be required to make the return trip by another street.

At Rochester, N. Y., the car tracks on residence streets are located on the parking at the side of the street. This is an unusual arrangement, but it possesses some advantages. 1. It separates the vehicular and car traffic, and prevents mutual interference. 2. It permits a narrower pavement. 3. It prevents disturbance of the pavement to repair the car track. 4. It lessens the danger of a passenger's being struck by another car or a vehicle in leaving a car. The objection to this arrangement is that it interferes with the grade of the driveways to private grounds.

471. STREET GRADES. The fixing of street grades is one of the most important functions of municipal engineering, since the grade system of the streets is the foundation of all municipal engineering matters. The grades should be established before the sewer system is planned; and if they are established before the property is improved. the problem is comparatively simple, since they may be laid chiefly with reference to obtaining desirable gradients for the street within proper limits of cost. But when buildings have been erected, sidewalks constructed, and trees planted, it is frequently extremely difficult to secure grades which will harmonize the various and conflicting interests.

472. Elements Governing Grades. The grades necessarily depend mainly upon the topography of the site: but in general the determination of the proper grade for a street requires the consideration of the following elements: (1) the drainage, (2) the cost of earthwork (3) the acccommodation of the traffic, (4) the effect upon the abutting property, and (5) the general appearance of the street.

473. *Drainage.* The streets are the natural drainage channels of the city; the lots must drain into them, and the house must drain into the sewers placed in the streets. When no storm-water sewers are to be constructed, the grades become very important, since the streets must provide for the surface drainage of the city, and particular consideration must be given to relative grades and gutter capacities in order to prevent the excessive concentration of storm water at the lower levels and to provide for its proper distribution and disposal.

474. *Cost of Earthwork.* Not infrequently the cost of making the excavations and embankments is given undue weight. The balancing of cuts and fills is often properly a controlling element in country road construction, but it should have relatively little weight in determining the grades of city streets. The expense for earthwork is incurred once for all, and a few hundred dollars more or less is usually unimportant in comparison with the expense of maintaining the street surface and the drainage system. and the cost of conducting traffic over the grades, and also in comparison with a better general appearance of the street.

475. *Accommodation of Traffic.* The question often is whether or not to secure ease of traction at the expense of increased cost of construction. The discussion in Chapter II, § 62–86, sheds a little light, and only a little, as to the proper method of answering this question. Apparently engineers are inclined to overestimate the disadvantage to traffic of a slight grade. Practical experience has demonstrated that there is not much difference in effect upon the cost of transportation between level roads and those having grades of 2 or 3 per cent unless such grades are very long or have an unusually smooth and well-kept surface,

476. *Effect upon Abutting Property.* The private interests of the property holder should be carefully considered; although it is frequently impossible to establish proper grades without injury to the adjoining property. The general question is how far private interests should be sacrificed to the general good. It is better that the city or the other residents on the street should pay the owner damages than that lasting detriment should be done to the appearance of the street or to the traffic.

477. *General Appearance.* Some attention should be paid to

the appearance of a longitudinal view of the pavement. It is desirable that the longitudinal grade be not changed so frequently as to give the street a wavy appearance. Further, the transverse grades at street intersections and on side hills should be so arranged as not to produce a confused appearance in looking along the street. The grades of the streets, both longitudinal and transverse, have a material effect upon the general appearance and beauty of the city.

478. Maximum Grade. In a general way the principles governing the determination of the permissible maximum grade of a city street are the same as for a country road, i. e., it is a question between the cost of operation on the one hand and the cost of construction and maintenance on the other, except that for a country road the cost of construction is chiefly the cost of moving the earth, while for a city street the cost of construction should also include the effect upon abutting property of high embankments or deep excavations, and except further that usually in the city heavy loads can take a circuitous route and avoid the maximum grade entirely. In determining the maximum grade for a street, the fact should not be overlooked that the smoother the pavement the more serious is a steep grade.

For a general discussion of the relationship between cost of construction and cost of operation as affecting the maximum grade, see Chapter II, Road Location—§ 71.

479. In the Borough of Manhattan, New York City, are some business streets having grades as steep as 6 per cent, and a number of residence streets have 10 per cent grades, and some have grades of 12, 15 and 18 per cent. Brooklyn, N. Y., has 4 per cent grades on business streets and 12 on residence ones. A number of cities have maximum grades on paved streets of 20 per cent—for example, Worcester, Mass., Syracuse, N. Y., Borough of Richmond, New York City, and Pittsburg, Pa. Burlington, Iowa, has an 80-foot street with a 24 per cent grade up which is laid a zigzag brick pavement 18 feet wide having a maximum grade of 14½ per cent with a minimum radius of the inside curb of 16 feet.

For a discussion of the maximum grade for each kind of pavement, see the heading Maximum Grades in the chapter treating that particular pavement.

It is usually considered that a grade steeper than 15 per cent is impracticable and dangerous even for light traffic; and therefore if this grade can not be obtained, the street should be divided into two parts separated by a terrace or stone wall, each portion being entered only at its intersection with the cross street. A 10 per cent grade is usually considered prohibitive for heavy loads; and 5 or 6 per cent is considered the limit on business streets.

480. The selection of the proper pavement for the maximum grade is a matter of great importance. It is usually held that sheet asphalt should not be laid on grades steeper than 2 to 3 per cent, although it has often been laid on 6 or 7 per cent grades, and in one instance on a 17 per cent grade (see § 676). Brick, or hard sandstone, or granite may be used upon the maximum grade. The sandstone and the granite blocks should be narrow and should be of a quality that does not wear smooth. It has been recommended to chamfer the corners of rectangular stone or wood blocks when laid upon steep grades, to give the horses a good foot-hold; but it is at least doubtful whether the benefit of a good footing is not neutralized by the increased tractive resistance. The joints should be filled with tar or hydraulic cement.

481. Minimum Grade. The street surface should have enough longitudinal slope to drain its surface well. For a discussion of the minimum grade permissible with macadam—a material much used for city pavements as well as for country roads,—see § 86. With a smooth and impenetrable pavement no ruts will be formed, and hence the determination of the minimum permissible grade is mainly a question of the grade of the gutter. If the drainage is carried away by under-ground storm-water sewers, the street may be perfectly level longitudinally, since the necessary grade for the gutters may be obtained by making them deeper as they approach the inlet to the sewer. For a further discussion of this phase of the subject, see Grade of Gutter—§ 505.

If it is inexpedient to vary the depth of the gutter (§ 504) or to increase the grade by constructing additional inlets and catch basins, it is necessary to secure the proper slope for the gutter by inserting a summit in the street solely for drainage purposes—usually referred to as an accommodation summit. However, it is undesirable that there should be frequent changes in the grade,

as they give the pavement an unpleasant wavy appearance when one looks along the street.

482. Grades at Street Intersections. One of the most important parts of the establishment of a system of street grades is the arrangement of the grades at street intersections. It is a common practice to establish only the grade of the intersection of the center lines of the streets; but this has often resulted in much confusion in determining the grade for the corners of the curbs, particularly where the two streets have considerably different grades. For example, in Fig. 84 assuming (for the present at least) that the curb

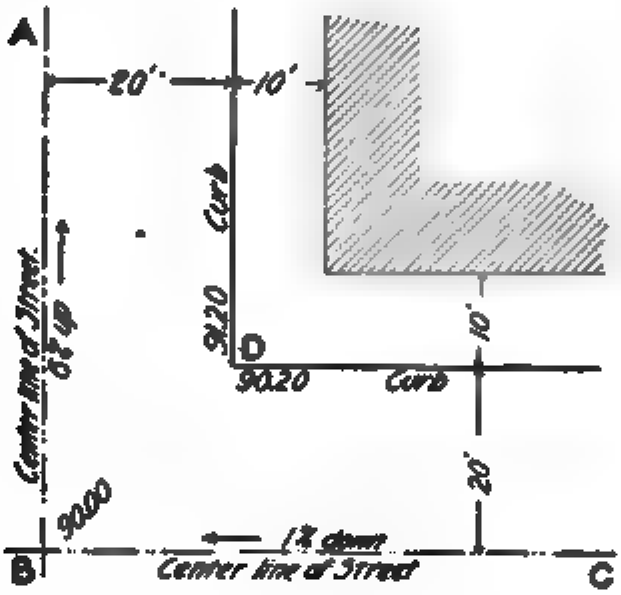


FIG 84—GRADE OF CURB AT STREET INTERSECTION.

is to be at the same elevation as the center of the street opposite, the elevation of the corner of the curb, *D*, as computed from the grade of *C B* is 90.20 ft.; while the elevation of the same point as computed from the grade of *B A* is 91.20 ft.—a difference of 1.0 foot. To obviate this source of confusion, the elevation of each corner of the curb and also of the intersections of the center lines should be established.

A similar confusion occurs in attempting to compute the elevation of the corner of the property, from the grade of the corner of the curb. For example in Fig. 85, assuming that the grade of the top of the curb is the same as that of the center of the street, and assuming that the sidewalk has a downward slope away from the property of 0.24 inch per foot (2 per cent), and also assuming that the grade of the corner of the curb, *D*, has been established as 80.00,

then the elevation of the corner of the property, *G*, as computed from the grade of the curb *D E* is 80.30 feet, while the elevation of the same point computed from the grade of the curb *D F* is 80.80 feet.

Some engineers advocate the establishment of the grade of the corner of the property and the determination of the grades of the curb and of the street therefrom; while others advocate establish-

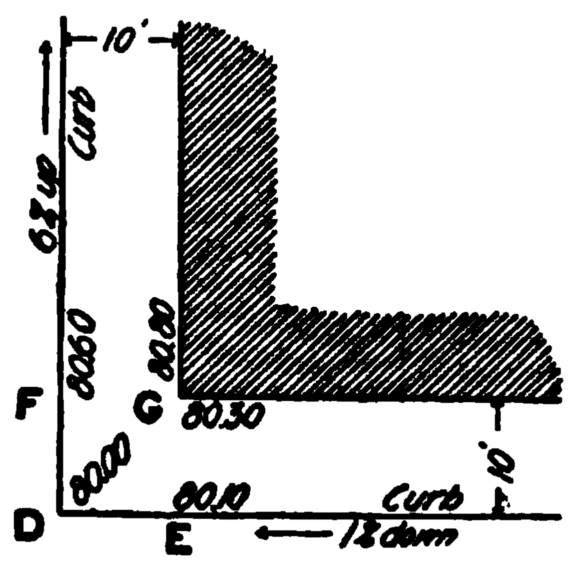


FIG. 85.—GRADE OF PROPERTY AT STREET INTERSECTIONS.

ing the grade of the corner of the curb and from that determining the grade of the corner of the property and also of the center of the street intersection. To be legal the grade must be fixed by ordinance. The courts generally hold that the "grade" is the top of the pavement in the center of the street; and therefore it is necessary to establish by ordinance the grade of the center of the street intersection. Further, to prevent misapprehension and error in computing the elevation of the corners of the curbs, and also to save the labor of computing them anew each time a lot is to be surveyed, it is wise to establish also the grade of the corner of the curb. The ordinance should distinctly state the method to be employed in computing the auxiliary grades, i. e., the grade of the sidewalk and of the corner of the property. Often the grades are established for only one street without due consideration of the intersecting street; and then when the second street is improved, the result is confusion, disputes, and sometimes suits for damages.

483. When the rate of grade of both streets is small, it is desirable that the entire street intersection from property line to property line, should be level, a condition which permits the continuation of the section of each roadway until they intersect, makes the

top of the curb at the four corners of the same elevation, and also allows the sidewalks at the corners to be level. That is to say, in Fig. 86, the four points marked *b* and all the points marked *a* are

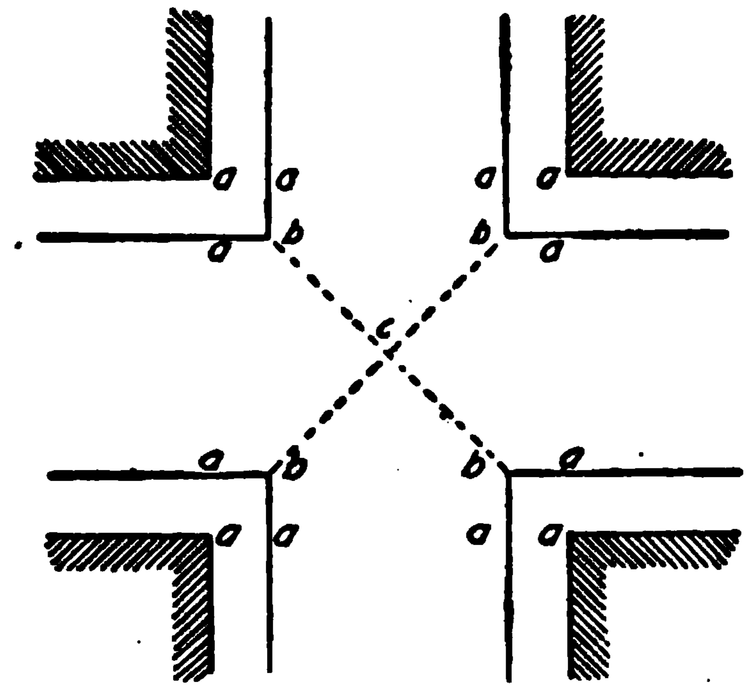


FIG. 86.—GRADE AT LEVEL STREET INTERSECTION.

in the same horizontal plane. Each street has its full crown on the line *b b*, and consequently there is a slight rise from *b* to *c*.

Where either or both streets have much inclination, it may not be wise to flatten out the intersection, and thereby increase the grade on the remainder of the street. Under these conditions, the best arrangement of the intersections is a matter requiring careful study and is one upon which there is much diversity of opinion. If steep grades are continued across intersections, they introduce side slopes in the streets thus crossed, which are troublesome and possibly dangerous—particularly to vehicles turning the upper corners. Such intersections are also objectionable on account of the difficulty of properly caring for the storm water. In residence districts it is usual to make the intersection "level from curb to curb"; that is, in Fig. 86, the four points marked *b* are in the same horizontal plane. The level places serve as breathing places, and lessen the danger of collision at the intersection. However, if the street has a considerable grade, a level intersection appears to have a decided pitch toward the hill, which gives the street an unpleasing appearance; and therefore under these conditions, it is better to apply, even in residence districts, the principle of the succeeding paragraph and give the intersection a moderate inclination down hill. If the intersection

has only enough inclination to seem level, the general appearance of a series of such intersections is pleasing, having the effect of a succession of terraces.

The following rule* for adjusting the grades at street intersections is frequently employed and apparently is the most complete of any that has been proposed. "In the business section all the street grades of 3 per cent or less should be continued unbroken over the intersection; and streets having a steeper grade than 3 per cent should have an intersection of 3 per cent between curb lines. The grade of the curb between the other curb line and the property line should in no case be greater than 8 per cent. The grade at the corner of the property should be determined by adding to each of the grades of the curb opposite the corner, the rise of the sidewalk and taking the mean." Fig. 87 shows the sev-

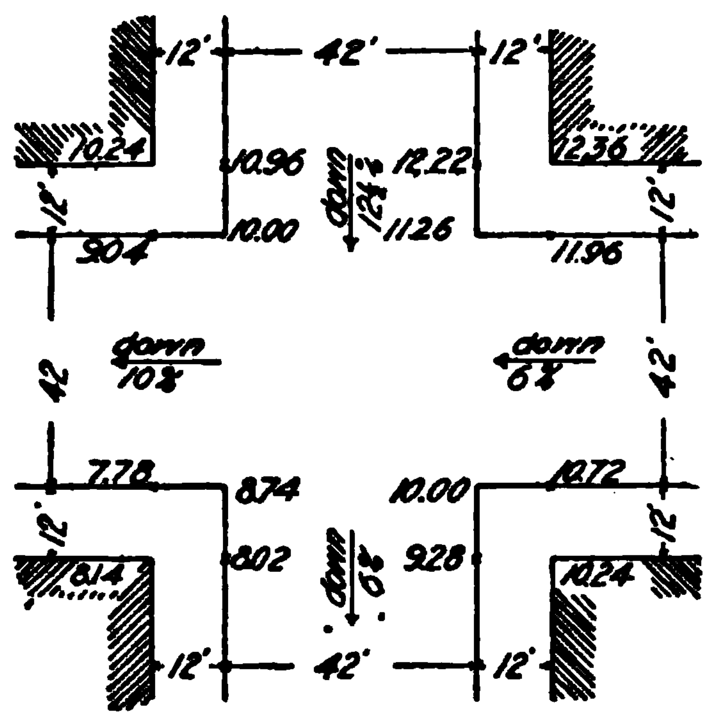


FIG 87.—GRADES AT INCLINED STREET INTERSECTION.

eral elevations of a street intersection adjusted according to the above rules, assuming the transverse slope of the sidewalk to be 2 per cent (practically ¼ inch per foot—the usual value).

The difficulty of adjusting the grades at an intersection is considerably increased if the two streets do not intersect at right angles. It is impossible to formulate any general rule, since each case must be decided according to the local conditions; and since

* Proposed by Messrs Rudolph Hering and Andrew Rosewater for the streets of Duluth, Minn., in a report dated March 7, 1890. Published in the Report of Board of Public Works, Duluth, Minn., for 1890, and re-published in *Engineering News*, Vol. 25, p. 148–49, and also in *Engineering Record*, Vol. 22, p. 53.

close observation and good judgment are required to secure a reasonably satisfactory adjustment.*

484. Notice that if either street has a grade and is carried past the intersection nominally unchanged, the area between the four curb corners and that immediately adjacent will be a warped surface. For example, in Fig. 88, if the street *S* has a descent as indicated and the street *W* is level, and the unchanged crowns of the street intersect at *C*, the area marked *w* must be raised to carry the upper side of the street *W* over the intersection, and the portions marked *v* must be raised to carry the street *S* over the lower side of the street *W*. If the grade of either street is small, this adjustment can be made by "warping in," or "boning in" the surface for a short distance by the eye.

485. Vertical Curves at Grade Intersection. It is frequently claimed that the grade should be carried straight through from street intersection to street intersection, i. e., that the grade should not be broken in the block. Apparently the reason for this practice is the claim that a break of grade between streets is unsightly. As usually put in, the angle of intersection is simply rounded off a little by eye; and if the change of grade is considerable, the appearance is not good. A change of grade in the block is nowise

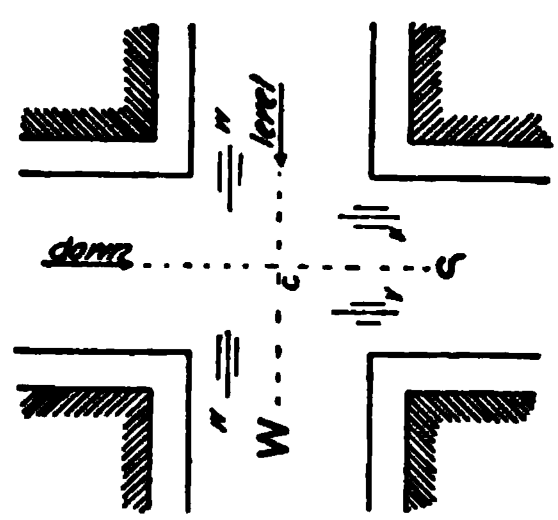


FIG 88.—A WARPED STREET INTERSECTION

different from a change at the street intersection, except that the former is a little more conspicuous. For both appearance and

* For some formulas to assist in this matter, see an article by William B. Fuller in Journal of the Associated Engineering Societies, Vol. 13, p. 658–60 or a duplicate of the same in *Engineering Record*, Vol. 22, p. 216. For an interesting and instructive account of the method of adjusting the grades at a number of complicated intersections, see an article by F. A. Calkins in *Engineering News*, Vol. 17, p. 134–35, and 150–51.

the comfort of the traffic, wherever there is considerable change of grade the two grade lines should be connected by a vertical curve; and if this is properly done, a break of grade in the block or elsewhere is unobjectionable. A vertical curve should be inserted at a change of grade either of the pavement or of the curb.

By breaking grade in the block, it is possible to fit the grade line more closely to the natural surface, and thereby to decrease the cost of construction, to lessen the damage to abutting property, and to improve the general appearance of the street.

486. A parabola is the best form for a vertical curve and is most easily put in. In Fig. 89, *A B* and *A C* represent two grade

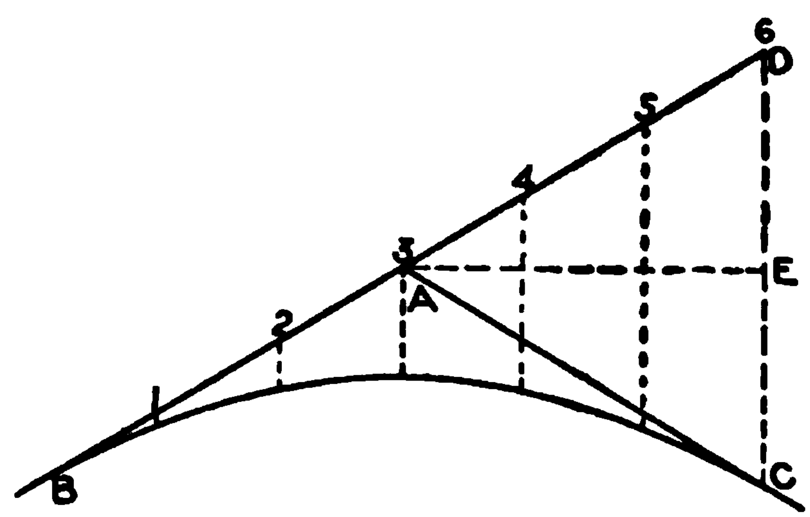


FIG. 89.—VERTICAL CURVE

lines meeting in the apex *A*, joined by the vertical parabola *B C*, which is tangent to the straight grade line at *B* and *C*. The curve may be located by measuring ordinates vertically below the points 1, 2, 3, etc. The tangent distances *A B* and *A C* are equal. *D E* is equal to the rise in half the length of the curve, i. e., from *B* to *A*; and *E C* is equal to the fall in the second half, i. e., from *A* to *C*. If n represents the number of equidistant points to be established on the curve (including the second tangent point, *C*), then the ordinate at the first point $= x = \frac{DE + EC}{n^2}$. The ordinate at any other point is equal to x times the square of the number of equal divisions between *B* and that point; that is, the ordinate from 2 is $4x$, from 3 is $9x$, from 4 is $16x$, from 5 is $25x$, and from 6 is $36x$. In actual work, the grade elevation of the points 1, 2, 3, etc., are to be worked out in the usual manner; from these elevations subtract the ordinates as computed above, and the remainder is the grade elevation of the respective points on the parabola *B C*.

The agreement of the elevation of the last point on the curve, 6 in Fig. 89, with the point C on the tangent, checks the work of computing the elevations.

If the second tangent, $A\,C$, is level, $E\,C$ in the above value for x is 0; and if the second tangent has an up grade, $E\,C$ is minus, and the numerator $= D\,E - E\,C$. If the first tangent is level, $D\,E = 0$; and if the first tangent has a down grade, $D\,E$ is minus, and the numerator $= E\,C - D\,E$. The principles deduced for Fig. 89 are equally true, if that diagram be turned upside down.

To secure the best results, there should be 15 feet of curve for each per cent of change of grade, although 10 feet per degree will give fair results. Long vertical curves make a graceful street. The effect of any proposed curve in lowering (or raising) the apex can be judged of beforehand by remembering that the distance from the apex A, Fig. 89, to the curve is equal to half of the difference in elevation between A and the mean of the elevations of B and C.

487. Crown of Pavement. The only reason for crowning a pavement, i. e., for making the center higher than the sides, is to afford surface drainage; and therefore the proper crown to be given to pavements will be considered under the head of Street Drainage—see § 509–14, Chapter X.

To make intelligible the discussion of the succeeding section, it is necessary to state here that in general the surface of the pavement consists either of two planes meeting at or near the center, or of a flat convex curve, usually the latter; and for present purposes it is sufficient to say that the average transverse slope is usually between 1 and 3 per cent (see § 513). The smoother the pavement and the better the construction, the less should be the crown.

488. Cross Section of Side-hill Streets. The arrangement of the cross section of a street upon a side hill is a matter requiring good judgment, that needless damage may not be done to the abutting property or that the general appearance of the street may not be uselessly sacrificed. In solving this problem no fixed rules can be laid down; but each case must be treated by itself, taking into account the local conditions. Fig. 90 shows the normal arrangement for a residence street on level ground; both footways are at the same elevation, the slope of the parking is the

same on the two sides, the tops of the curbs are at the same level, the gutters are of the same depth, and the surface of the street rises equally from each side to the center. The normal section for a business street would be the same except that the sidewalk

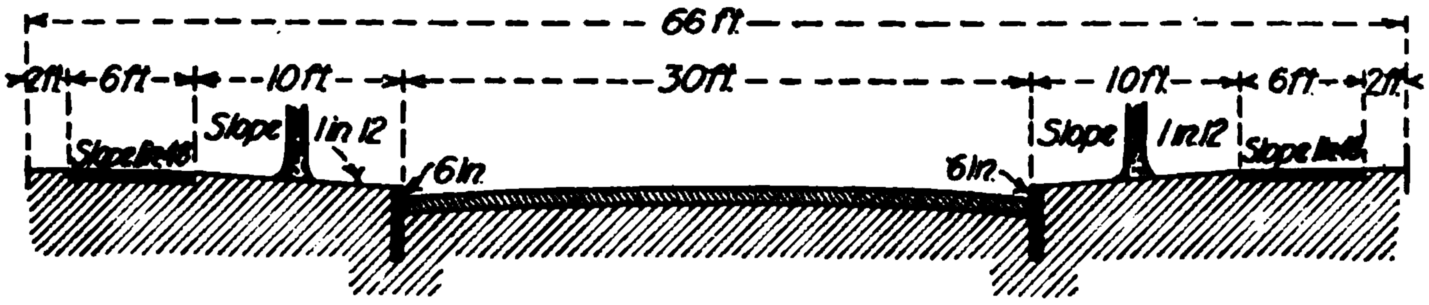


FIG. 90.—CROSS SECTION OF STREET ON LEVEL GROUND.

would occupy all the space between the curb and the building line. On a side-hill street the above conditions can not always be realized; and various expedients must be resorted to, depending upon the difference in elevation of the two sides of the street. The following are some of the common expedients.

1. If the difference is not very great, the curbs may be set at the same level, and one sidewalk may be placed higher than the other, the grade of the parking being different on the two sides. On a business street, where there is no parking, the slope of the footway may be different on the two sides. With sidewalks consisting of stone slabs, cement, or asphalt, a slope of at least ⅛ of an inch per foot (1 in 96) is required for drainage, and a slope of more than ⅜ of an inch per foot (1 in 32) is dangerous when covered with ice or snow.

2. A slight difference of level may be overcome by raising the curb, i. e., by increasing the depth of the gutter, on the low side, and lowering the curb on the high side, the crown of the pavement remaining symmetrical about the longitudinal center line. Fig. 91 shows an actual section of a street arranged on this plan.*

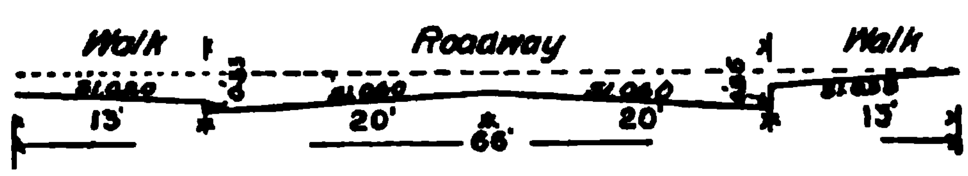


FIG. 91.—CROSS SECTION OF SIDE-HILL STREET.

Except under extreme conditions, the curb should not show more than 10 inches because of the difficulty of stepping to or from

* Trans. Amer. Soc. of Civil Engineers, Vol. 42, p. 5.

the pavement, nor less than three inches because of the danger of its being overflowed when the gutter is full of melting snow.

Sometimes a double curve is employed with a horizontal tread about 1 foot wide between the two risers. The combined concrete curb and gutter (§ 522) lends itself most readily to this form of construction. Fig. 92 shows such an arrangement.* The ob-

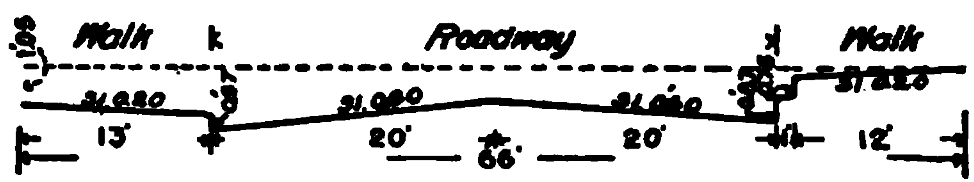


FIG. 92.—DOUBLE CURB FOR SIDE-HILL STREET.

jections to the double curve are: 1, its cost; 2, the difficulty of keeping the step neat and sanitary; and 3, it lessens the width available for roadway and sidewalk. In practice these objections have not proved to be serious. Instead of the double curb, it has been proposed to place the second step at the area line or property line, to which arrangement the owner is liable to object, particularly on a business street.

3. A slight difference may also be overcome by making the upper side of the pavement nearly level and giving the lower half the normal slope.

4. The crown may be moved toward the high side of the street, the profile for each side being determined in the usual way; that is, the surface of the pavement may be two planes meeting at the crown with the intersection rounded off a little, or it may be two arcs of a circle or a parabola tangent to a horizontal line at the high point (see § 310 and § 512). Fig. 93 is an actual example

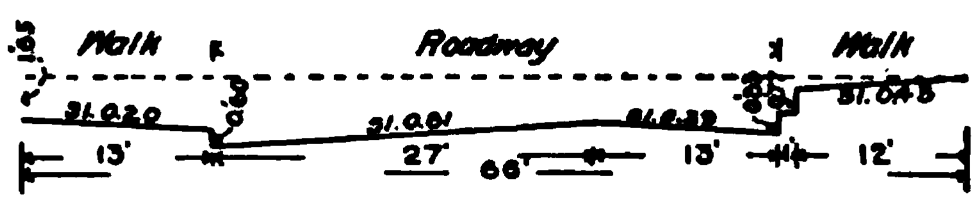


FIG. 93.—CROSS SECTION OF STREET ON A SIDE HILL.

of this method of solution.* If the longitudinal grade is considerable, as it usually is under such circumstances, there is no objection to the upper side of the street's being exactly level transversely. The extreme of this solution is to make the surface of the pave-

* Trans. Amer. Soc. of Civil Engineers, Vol. 42, p. 5.

ment a right line from the upper to the lower side—see Fig. 94. This arrangement has been objected to on account of its throw-

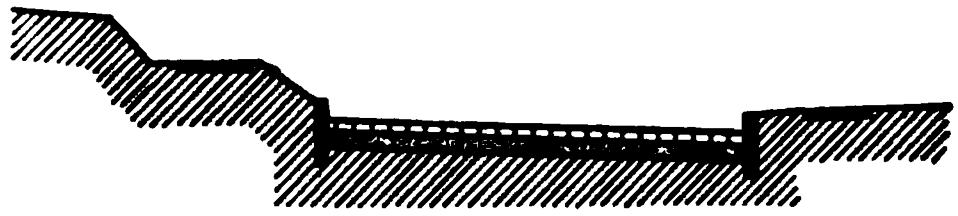


FIG. 94.—CROSS SECTION OF STREET ON A SIDE HILL.

ing all of the drainage to one side of the street; but this is not a serious objection, particularly if there is a considerable longitudinal grade, as there is usually.

5. Where there is a considerable difference of elevation on a residence street, it is sometimes wise to place the footway next to the curb, and to allow the slope of the parking to unite with that of the property—see Fig. 95.

FIG. 95.—CROSS SECTION OF SIDE-HILL STREET.

6. When any or all of the above solutions fail, it may be necessary to terrace the street and to construct an upper and a lower roadway as shown in Fig. 96.

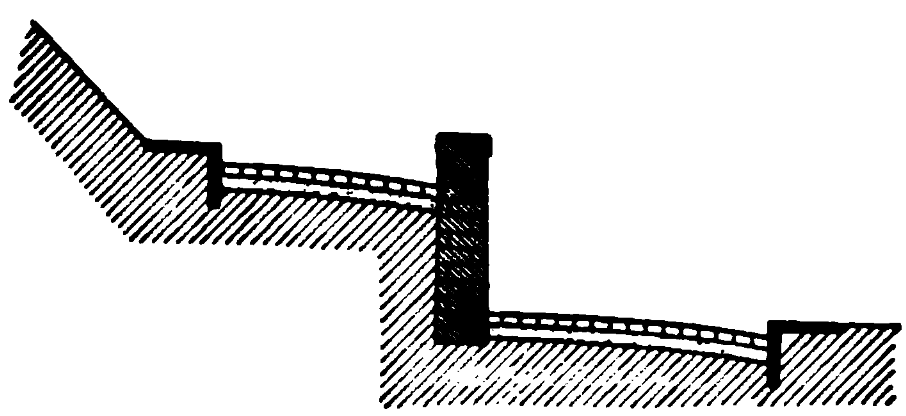


FIG. 96.—CROSS SECTION OF SIDE-HILL STREET.

489. When the street contains one or more street-car tracks, the problem of arranging a cross section on the side of a hill is still more complicated. It is necessary that the two sides of a track shall be at least nearly on the same level; but it is not necessary that the two tracks shall be at the same elevation. A difference in elevation of $\frac{3}{4}$ of an inch between rails of the same track and of 3 inches between adjoining tracks is permissible.

490. PLANS AND SPECIFICATIONS. When a pavement is to be constructed by contract, as is almost the universal practice in

this country, the engineer prepares plans and specifications which constitute a detailed description of the manner in which the work is to be done.

The plans should consist of any drawings necessary to make clear the method of doing the work. Usually no drawings are submitted except a profile, and sometimes also a cross section of the proposed pavement. Occasionally drawings are given showing the method of setting the curb, laying the gutter, placing the inlets, and paving around manholes, against street-car rails, at street intersections, etc. The city engineer stakes out the work, and hence no drawings are required to show the boundaries of the proposed improvement.

The specifications should consist of two distinct parts: (1) full particulars as to the business portion of the contract and the relation of the several parties, and (2) a technical description of the materials to be used and the methods to be employed. The first are substantially the same for all forms of pavements, while the second vary with the materials used. For a full and complete presentation of the business part of pavement specifications, see Johnson's Engineering Contracts and Specifications;* the technical parts will be referred to in the respective chapters following.

491. STREET TREES. It is always desirable both for the shade and for the appearance, and usually possible, to have the streets, at least those devoted to residences, lined with trees on each side. Although trees in the streets have an important sanitary and æsthetic value, opinions differ regarding the proper responsibility for them. One view vests all right and title to the tree in the owner of the property before which it stands; and the other asserts that the trees belong to the city at large and that the individual has no more right to the tree in front of his property than has any other citizen. In the first case, the planting of the tree, its kind, position, and care depend upon the public spirit of the property holder; and as a result the street presents a motley, straggling appearance often with no trees where they are most needed for the

* Engineering Contracts and Specifications, by J. B. Johnson, Engineering News Publishing Co., New York City, 1895. 417 pp. 6 × 9″. $3.50. This volume contains a brief but excellent synopsis of the law of contracts with illustrative examples of the general and technical clauses of various engineering specifications.

best general effect. Without some degree of public control, it is impossible even to approximate the best results of tree planting; but fortunately the number of cities is rapidly increasing in which the street trees are under the control of the municipal authorities.

In planning a system of streets, the location of the trees should be definitely provided for. They should be located in the grass plats between the sidewalk and the edge of the pavement, and at a sufficient distance from both the sidewalk and the pavement that there will be no danger of the roots lifting either. The trees should be spaced in the row so as to permit each when fully grown to spread to its natural dimensions, which usually requires a space of 25 to 40 feet. Not infrequently trees are planted much too close—particularly in the fertile and originally treeless prairies of the Mississippi Valley;—and are left to crowd each other and to prevent a symmetrical growth. In planting trees, it is well to alternate those of rapid growth with those which mature more slowly; and then as the latter increase in size and demand more room, the former, having served their temporary purpose, can be removed. Increased stateliness, impressiveness, and charm is secured if the trees, at least the permanent ones, on any one thoroughfare are of one variety. Different streets can have different kinds of trees, since in nearly all cities there are a large number of suitable varieties available.

492. In most states there are one or more cities that have obtained—either officially or by volunteer civic-improvement societies—valuable experience as to the varieties best suited to the environment, from whom data can doubtless be obtained by those desiring information concerning the kind of trees to plant in the streets of any particular city.

493. The following are the requirements for a street tree adopted by a commission of experts for Washington City.* "1. A somewhat compact stateliness and symmetry of growth. as distinguished from a low spreading or pendant form, so that the stem may reach a sufficient height to allow free circulation of air below the branches. 2. An ample supply of expansive foliage of bright early spring verdure, and rich in the variety of colors and

* Proc. Amer. Soc. Municipal Improvements, Vol. 5, p. 97.

tints assumed during autumn. 3. Healthiness, so far as being exempt from constitutional diseases, as well as by maladies frequently engendered by peculiarities of soil and atmosphere impurities. 4. Cleanliness, characterized by a persistency of foliage during the summer, freedom from fading flowers, and exemption from the attacks of noxious insects. 5. It should be easily transplanted, of moderately vigorous growth, and not inclined to throw up shoots from the root or lower portion of the stem. A tree of extremely rapid growth is generally short-lived. 6. The branches should be elastic rather than brittle, that they may withstand heavy storms; and lastly, there should be no offensive odor from foliage or flowers."

Of course, no tree planted amid the artificial conditions found in a large city will fully meet such rigid requirements. In 1872, at the commencement of systematic tree planting, the above commission recommended the following list of trees. The Silver Maple (Acer dasycarpum), the American Linden (Tilia americana), the European Sycamore Maple (Acer pseudo-platanus) and the American Elm (Ulmus americana) are thought to fill all the above requirements when not subjected to the attacks of insects. The Tulip Tree (Liriodendron tulipifera), Sugar Maple (Acer saccharinum), Sweet Gum (Liquidamber styraciflua), and the Red Maple (Acer rubrum) are the most beautiful of trees, their only drawback being that of not growing freely after transplanting. The Norway Maple (Acer platanoides), the Negundo (Acer negundo), and the American Ash (Fraximus americana) are recommended for certain places. The Button-woods or Planes (Platanus occidentalis and Platanus orientalis) are rapid growing, and for wide avenues are effective trees.

As a result of twenty-five years' experience, the trees are ranked as follows: * "Silver Maple, Norway Maple, and Eastern Plane side by side in the first rank; then the Ginkgo, and Western Plane; and last American Linden, Oak, and Sugar Maple."

* Proc Amer. Soc. Municipal Improvements, Vol. 5, p. 98.

CHAPTER X.

STREET DRAINAGE.

495. The thorough drainage of a street involves four elements: (1) the surface drainage, (2) the gutters, (3) the catch basins, and (4) the underdrainage. They will be considered in the reverse order.

496. Subdrainage. The underdrainage of a street is the first step toward paving it. Without thorough subdrainage a pavement is likely to settle here and there, forming unsightly depressions on the surface, and possibly breaking through. The subsoil may be drained by one or more lines of porous tile as described in § 98–109; but as a rule the surface and underground waters are both collected in the same drain, and therefore it is advisable to lay a line of tile at each side of the street or to construct a larger conduit under the center of the street. Since the pavement is practically impervious to water, a third line of tile under the middle of the pavement is unnecessary, however wet and retentive the soil originally.

If there is a grass plat between the pavement and sidewalk, as is usual on residence streets, the tile should be laid under the outer edge of the parking or grass plat; and if there is no parking, the tile should be laid under the gutter. The deeper the tile the better the drainage and the less the liability of its becoming choked with tree roots. The tile should not be too small, since it is to carry both underground and surface water—the latter from a smooth and impervious pavement.

The formula for size of tile for the drainage of earth roads (§ 103) is worthless for pavements, since in cities a large proportion of the rain falls upon impervious roofs, pavements, sidewalks, etc., and nearly all speedily reaches the storm-water sewers. This subject has been very carefully studied in connection with the

design of sewers, and the reader is referred to treatises on that subject, for further information concerning the size of drains or storm-water sewers required.*

497. CATCH BASINS. The catch basin is a pit to receive the drainage from the surface of the street, in which is deposited the sand and other solid matter, and from which the water is discharged into the sewer or storm-water drain. A catch basin should fulfill the following conditions: (1) The inlet should offer the least possible obstruction to traffic, should have sufficient capacity to pass speedily all the water reaching it, and should not easily be choked by leaves, paper, straw, etc. (2) The capacity below the outlet should be sufficient to retain all sand and road detritus and thus prevent it from reaching the sewer, and will depend upon the area drained and the intervals between cleanings. (3) The water level should be low enough to prevent freezing. (4) The construction should be such that the pit may be easily cleaned out. (5) The pipe connecting the basin with the sewer should have sufficient capacity, and should be so constructed as to be easily freed of any obstruction. (6) It is desirable that the outlet should be trapped so as to prevent floating debris from reaching the sewer. (7) If the catch basin discharges into a sewer which also carries house sewage, the end of the outlet pipe should be trapped to prevent the escape of air from the sewer to the street through the catch basin.

498. The Construction. Catch basins are usually built of brick masonry, and plastered on the inside, at least up to the water line. Fig. 97, page 337, the standard of Champaign, Ill.,† is a good form. The opening of the inlet is protected by six half-inch iron rods. The several parts of the cast-iron top are $\frac{3}{8}$ and $\frac{1}{2}$ inch thick; and the total weight of the castings is 162 pounds The pit requires 1,000 brick. The total cost of the catch basin when laid in 1 to 2 natural cement mortar is $17.00 to $19.00, including castings, excavation and the vitrified elbow.

Fig. 98, page 338, shows the standard catch basin of Prov-

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* For example, see Folwell's Sewerage, p. 44–73. 3rd edition. John Wiley & Sons, New York City, 1900.

† By courtesy of W. H. Tarrant, City Engineer.

idence, R. I.* This form differs from that shown in Fig 97 in the form of the inlet and of the trap for the outlet. The latter is made

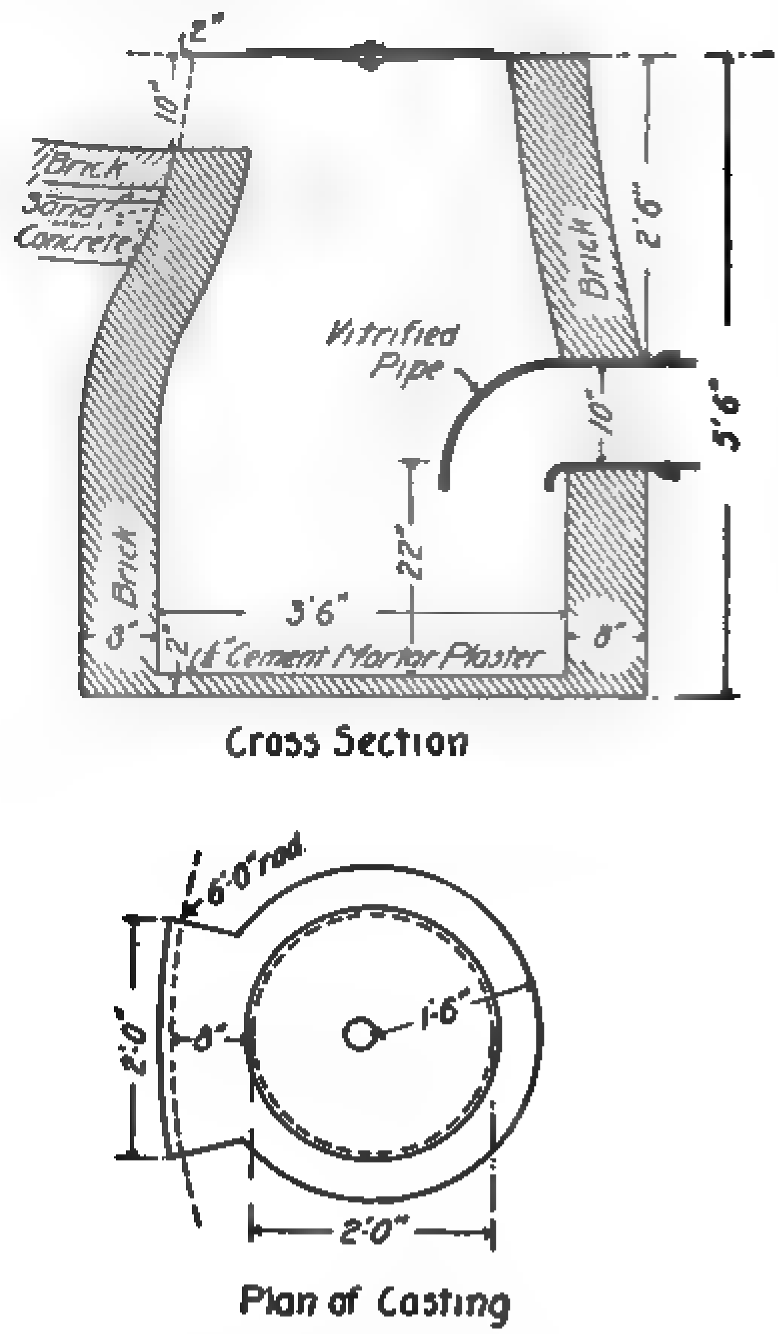
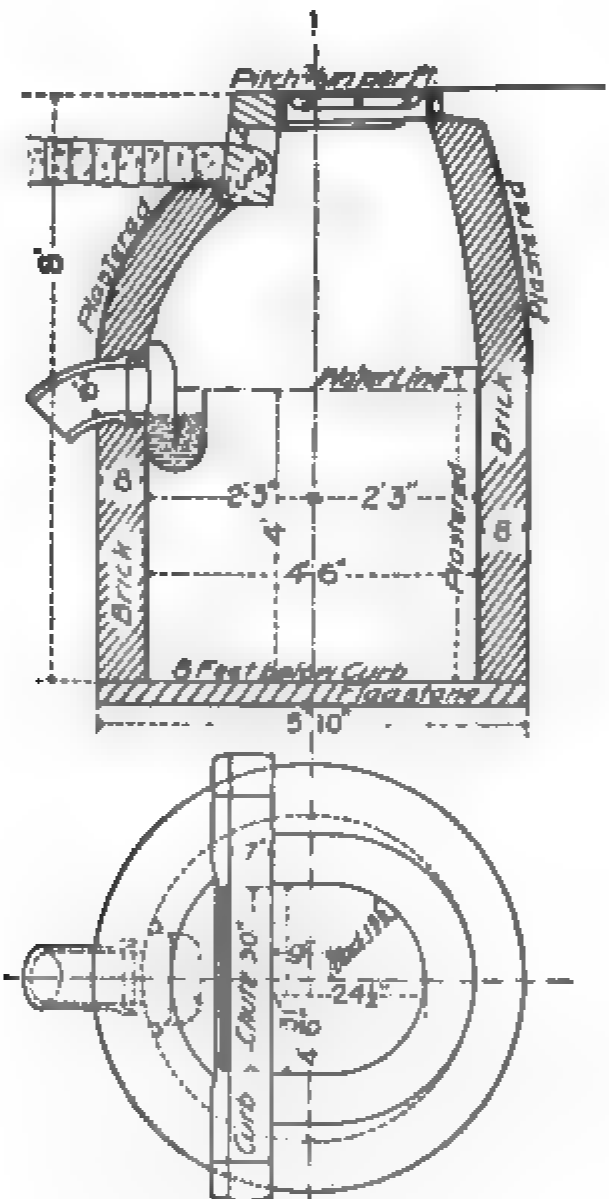


FIG. 97.—CHAMPAIGN CATCH BASIN.

of iron cast in a single piece, and is somewhat complicated in form, but a careful study of the two views shown in Fig. 98 will make the construction reasonably clear. The seal in Fig. 98 is better than that in Fig. 97; but the former is used only with storm-water sewers, and for such use the trap is sufficient. Not infrequently, however the outlet of the catch basin is left untrapped; and sometimes an inlet is connected to a sewer without the inter-

* By courtesy of Otis F. Clapp, City Engineer.

vention of either a catch basin or a trap. This practice is likely to clog the sewer.



PLAN WITHOUT MANHOLE FRAME

FIG. 98.—PROVIDENCE CATCH BASIN.

Fig. 99, page 339, is the standard for Milwaukee, Wis.* This diagram is presented to show (1) the form of the inlet, (2) the method of preventing floating debris from entering the outlet, and (3) the method of ventilating the sewer.

Fig. 100, page 339, shows the standard form in St. Pancras Vestry, London, England.†

In England many earthenware catch basins or "gully pits" are used. Some of these forms are quite complicated. American

* By courtesy of C. J. Poetsch, City Engineer

† From a special report by William Nisbet Blair, Vestry Engineer.

engineers object to earthenware pits on account of (1) their limited size, (2) their great cost, and (3) their liability to be broken by the weight and jar of the street traffic.

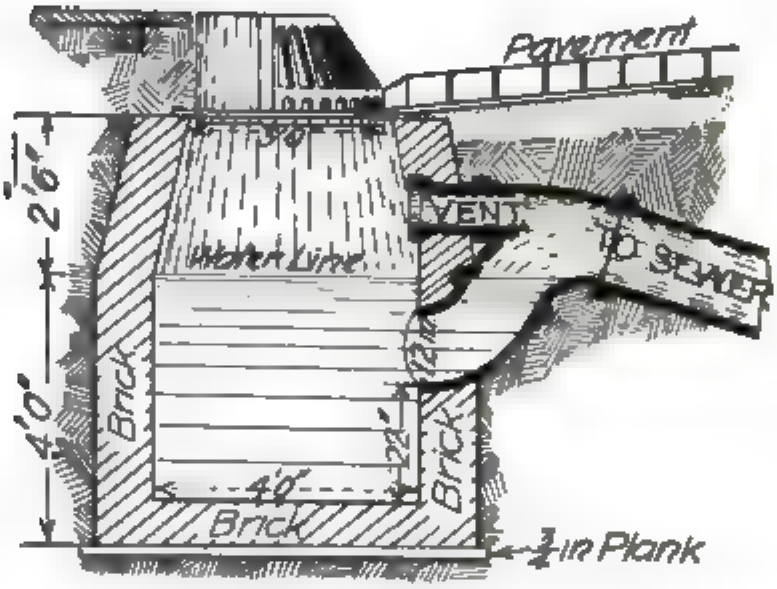


FIG. 99.—MILWAUKEE CATCH BASIN.

499. Location. The catch basin is usually placed near the curb with the cover in the sidewalk or the parking. It is objectionable to have the cover in the sidewalk, since (1) the cover itself is some-

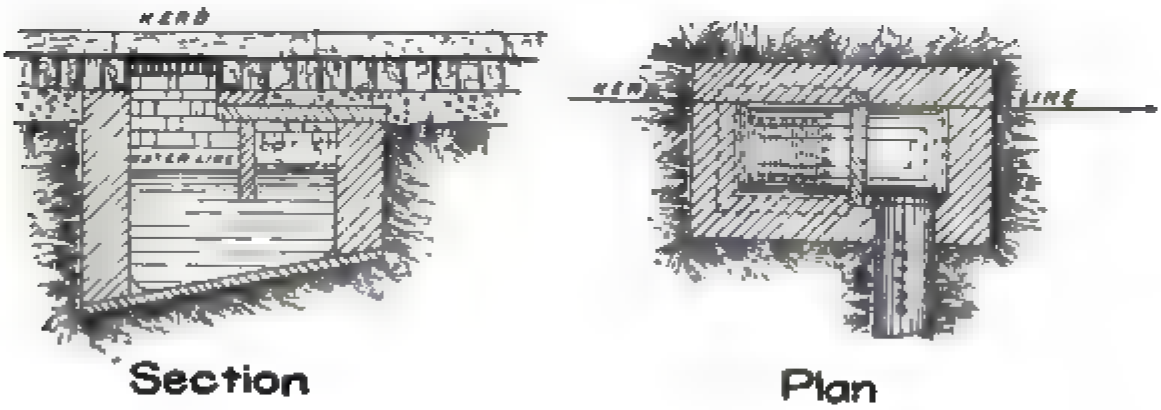


FIG. 100.—ST. PANCRAS CATCH BASIN.

thing of an obstruction to travel and is dangerous when it wears smooth or is covered with snow, (2) the clearing of the pit seriously interferes with the convenient use of the footway, and (3) in emptying the pit the sludge is likely to be spilled on the footway, and at best the odor is offensive. In some cities these objections are eliminated by placing the inlet at the curb line and conducting the drainage to a catch basin near the center of the street, one basin serving for two or more inlets. Notice that the catch basin shown in Fig. 100 cleans out in the gutter.

It is customary to place a catch basin at the corner of the curb. For additional objections to this location, see § 506.

The number and capacity of catch basins will depend upon the area drained, the amount of rain, the grade of the gutter, etc. On streets having light or level longitudinal grades catch basins may be constructed at intervals along the gutter as the circumstances require.

500. Form of Cover. When a catch basin or sewer manhole is located in a pavement, the shape and the surface of the cover require attention. The upper surface of the cover and also of its frame should be covered with projections to afford a good foothold and to prevent it from wearing slippery. The best form for the frame depends upon the material of the pavement. For macadam and asphalt the round frame is best, since it offers least obstruction to traffic; the next best form is a square frame set diagonally to the line of travel. For a pavement made of bricks or stone blocks, the frame set with its sides parallel to the length of the street is best, because the bricks or blocks can be most closely fitted against this form. In Europe and in many American cities, it is customary to use only a square form, and to set it diagonally in macadam and asphalt pavements, and square in stone block and brick.

Often water-gate or stop-box covers are round in plan and have a convex surface, although the convex surface is very objectionable. The better form is a cover round in plan with a flat recessed top set flush with the pavement. Preferably the portion below the ground should be provided with a cast screw for adjusting the height. This form may be had of dealers in street-drainage goods.

501. The Inlet. In a general way, there are stone and cast-iron inlets. The former consist either of an opening between a stone cover and a stone floor, or a slot through the stone curb (see Fig. 98, page 338). This form is usually entirely open, but it is sometimes barred with one or two horizontal iron rods.

There are a great variety of cast-iron inlets on the market, which may be classified as being straight or curved, and also as having a vertical or a horizontal opening. Fig. 101, page 341, shows an unprotected straight vertical inlet. Sometimes the opening is protected by one or more horizontal or vertical rods. The latter are the better, as they offer greater protection against the entrance of

debris—particularly sticks and boards. Fig. 102 shows a vertical front curved for a corner, having vertical bars. Fig. 103 and 104 are two styles of a form having both a vertical and a horizontal opening. Notice that Fig. 100, page 339, has only a horizontal open-

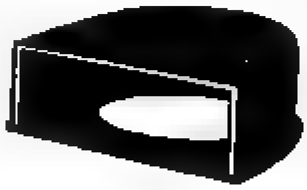


FIG. 101.

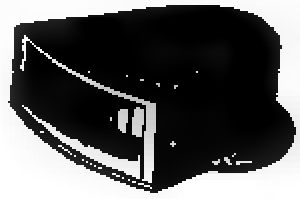


FIG. 102.

ing. A horizontal opening is not so good as a vertical one, since the former is easily stopped by a few leaves, and the accumulation of water makes the stoppage more complete; while the barred vertical opening is less easily obstructed, and as the water rises it can pour over the obstruction already formed.

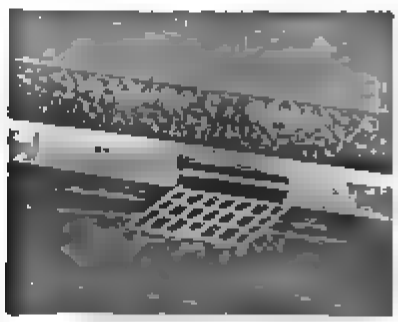


FIG. 103.

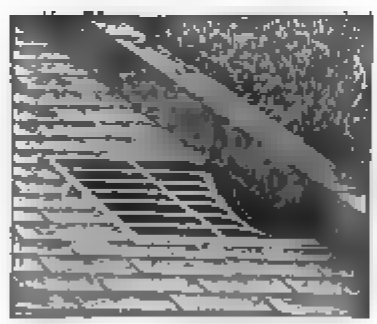


FIG. 104.

502. Inlet without Catch Basin. It is sometimes desirable to connect two or more inlets to one catch basin—for example, see § 507. There are various forms of such inlets on the market and many cities have their own special designs. Fig. 105, page 342, shows the form of inlet used in such a case at Omaha, Nebraska.* The entrance A is reduced by cast ribs to three openings $6'' \times 9''$ at the top and $4\frac{3}{4}'' \times 2''$ openings at the bottom. The section B is rectangular in plan at both top and bottom. The section C is rectangular at the top and circular at the bottom, and fits into the hub of a vitrified elbow. Fig. 106, page 342, shows a commercial form of inlet, which has an adjustable curb. It is made to fit various sizes of outlet pipe.

*By courtesy of Andrew Rosewater, City Engineer.

503. GUTTERS. The Material. Ordinarily the surface of the pavement adjacent to the curb serves as a channel to convey the drainage to the nearest inlet, i. e., the gutter is formed of the same material as the pavement. With an asphalt or macadam pavement, it is customary to lay brick or stone blocks in the gutters—with asphalt to prevent its deterioration from being continually covered with mud and water, and with macadam to prevent flowing water from disintegrating it.

A combined concrete curb and gutter (§ 522) is frequently used, particularly with asphalt, brick, or macadam on residence streets.

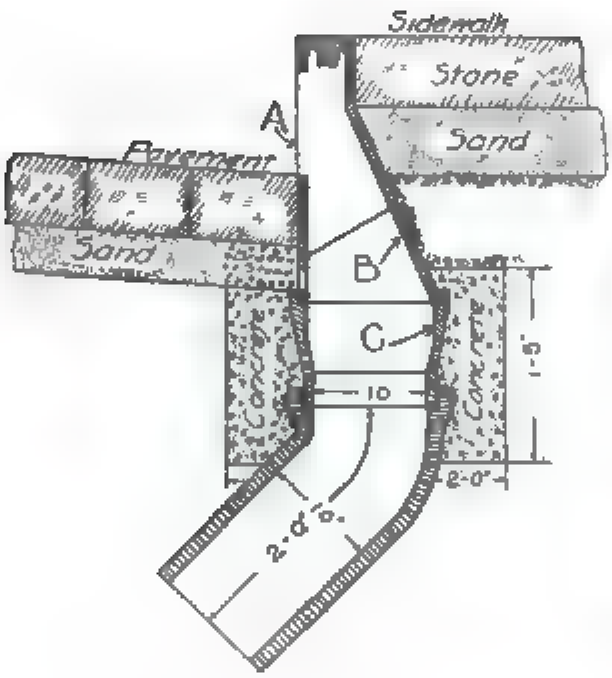


FIG. 105—OMAHA INLET WITHOUT CATCH BASIN.

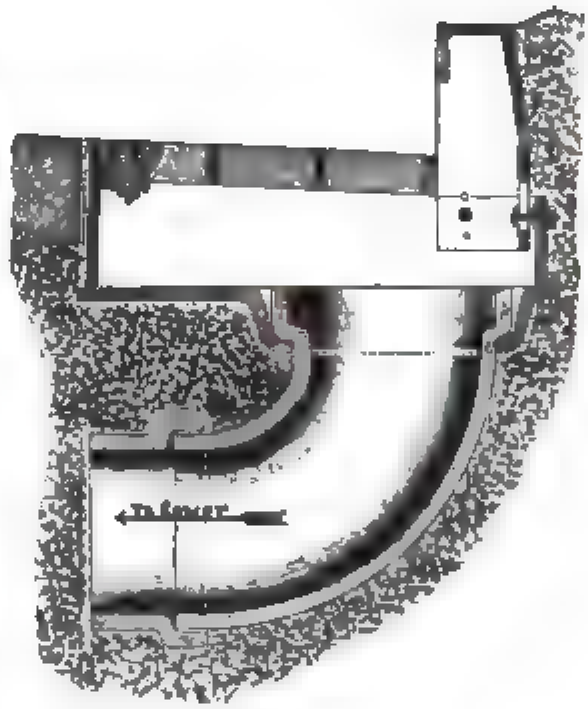


FIG. 106.—COMMERCIAL INLET WITHOUT CATCH BASIN.

A concrete gutter is objectionable on a macadamized street, on account of the crushed stone's wearing below the edge of the gutter, a condition which interferes with the drainage; but if the macadam surface is reasonably well cared for, this objection is not serious. A concrete gutter has been objected to for any pavement owing to the liability of a rut to form along its outer edge. In practice neither of these objections has proved to be serious. A concrete gutter is more efficient and looks better than any other material except asphalt.

Usually the gutter is formed by continuing the ordinary slope of the pavement until it intersects the curb; but occasionally the

outer edge of the pavement is given an upward inclination, thus forming a flat V-shaped channel a little way from the curb. This construction makes an excellent channel for the water, but prevents the driving of a carriage close enough to the curb to allow people to step in or out easily.

In some cases the curb is set and the gutter formed before the pavement is laid, in which case the curb and gutter are constructed as they would have been if the street were to be paved,—the gutter being composed of stone blocks, brick, or concrete (§ 520). Sometimes a street is macadamized or graveled when it is not desired to incur the expense of setting a curb, in which case the gutter is built of cobble stones, or stone blocks, or brick, in the form of a very flat V with the side next the property much the steeper.

504. Depth. Where a curb is used, the gutter should not be so deep as to present a high step for pedestrians, nor so shallow as to be in danger of being overflowed. Not infrequently gutters are made needlessly deep. It is easier to keep a curb in line with a shallow gutter than a deep one. On streets having a considerable longitudinal grade the gutter can have a uniform depth, inlets being inserted to draw off the surplus water; but on streets having nearly level grades, the gutter must increase in depth as the inlet is approached. This can be done with a stone curb, but not with a combination concrete curb and gutter (§ 522), since the latter is made in moulds and hence must have a uniform cross section; and therefore with a concrete curb and gutter, it may be necessary to put a summit in the pavement to secure proper drainage of the gutters. Except in extreme cases, the gutter should not be deeper than 9 inches nor shallower than 3 inches; and ordinarily it should not be more than 8 nor less than 4 inches—usually it is 5 or 6 inches.

It may be necessary to modify the preceding rules when one side of the street is higher than the other (see § 488). In localities where there is a good deal of snow, the gutter must be deeper than stated above, for shallow gutters readily become clogged with snow and slush. In some northern cities, the snow is habitually allowed to pack upon the surface of the street to a depth of 6 or more inches, in which places the depth of the curb must be extremely deep to prevent the melting snow and water from filling the gutter and flowing over the sidewalk into the basements.

505. Grade. For most materials with which gutters are paved, it is improbable that the grade will be so steep as to do serious harm. Crushed stone and gravel are exceptions to this rule, however, and these materials must not be laid on too steep a grade. They may be used on a 2 per cent grade provided the volume of water is not too great.

The minimum grade permissible in the gutter will depend chiefly upon the material with which it is paved, but somewhat upon the cost of catch basins. Almost any grade can be obtained by establishing catch basins close together and raising the gutter half way between them. In a number of cities the minimum grade of gutters paved with granite blocks, brick, rectangular wood blocks, or macadam is 1 in 300 or 400. Except under very favorable circumstances, a slope of 1 in 200, ½ of 1 per cent, should be regarded as the minimum.

Asphalt decays if continually wet, and therefore the condition governing the minimum permissible grade is different for that than that for other materials. With a slope of less than 1 per cent, the gutter will not keep itself clean, consequently the asphalt will decay owing to the action of mud and water; and hence asphalt should not be laid in a gutter having a fall of less than 1 in 100. If this fall can not be obtained, a concrete gutter should be used, or the gutter should be paved with vitrified brick or carefully dressed granite blocks.

506. DRAINAGE AT STREET INTERSECTION. In most cities it is customary to construct catch basins at the corner of the curb, using an inlet with a curved face. This practice is very objectionable.

If the walk across the street is elevated above the pavement, it is necessary either to carry the water under the walk in a pipe, or to stop the cross walk within a short distance of the curb to leave a channel for the water. The latter method is necessary where there is much water. Frequently this channel is left open at the top, and sometimes it is covered with a cast-iron plate with one edge resting in a rabbet in the curb and the opposite one in a head stone or false curb set at the end of the cross walk. The covered gutter is much better than the open one, although the cast plates are frequently struck by wheels and broken. This solution of the problem is further objectionable since a wheel in turning the corner must sur-

mount the first raised cross walk, then descend to the bottom of the gutter, and finally climb over the second cross walk. The face of the inlet usually has a depth of 8 to 12 inches below the top of the curb; and hence if the sidewalks are wide or the parking is narrow, the shock to a vehicle going around such a corner is considerable.

If the cross walk is not elevated, the step from the curb to the bottom of the gutter is uncomfortably high, and besides pedestrians are compelled to cross the gutter where there is the most water.

507. A much better arrangement than either of the above is to place an inlet at each side of the corner. Each inlet may have its own catch basin, or the two may connect with a single pit by means of tile or vitrified pipe underground. Fig. 107 shows such an arrangement. Instead of this plan, the two inlets at each of the four corners of the street intersection may be connected with a single catch basin placed in the middle of the intersection or in other suitable location. The inlet not connected directly with a catch basin can be made by inserting the hub of a curved vitrified pipe in the bottom of a cast inlet box (see Fig. 105 and 106, page 342).

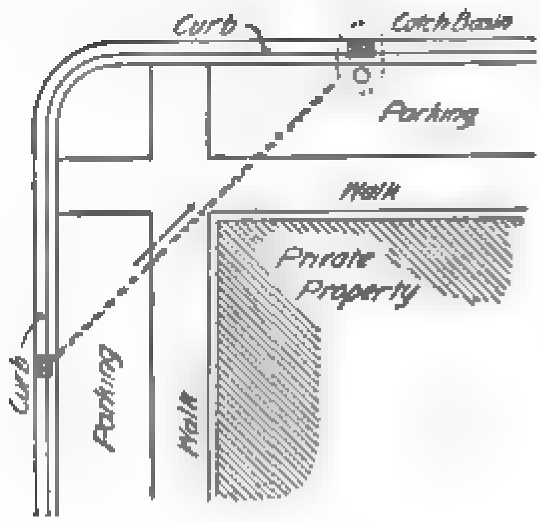


FIG. 107.—INLETS AT STREET CORNER.

The advantage of the method shown in Fig. 107 is that it allows the intersection to be paved almost level with the top of the curb, and hence there is no obstruction to either pedestrian or vehicular traffic. The only objection to it is the expense for either the extra catch basin or the extra inlet and the connecting pipe, but the advantage is well worth this comparatively small expense.

508. Where there are no storm-water sewers, the gutter is sometimes carried across the street intersection. This is objectionable at any season, and particularly so when the gutter is filled with snow or ice. If the gutter is deep or the grade is steep, the water may be carried under the intersection by a shallow culvert with cast-iron top, or better in a cast-iron pipe; but if the gutter is shallow or the grade nearly level, the road surface should be raised a

little to give room for a cast-iron storm-water drain under the roadway. The elevated intersection may be a slight obstruction to travel, but it is preferable to two open gutters.

509. Surface Drainage. The drainage of the surface of the pavement is provided for by making the center of the pavement higher than the sides. The principle governing the amount of crown for pavements is somewhat different from that of earth, gravel, or macadam roads. First, a hard, smooth and practically impervious pavement needs no crown for the drainage of the surface; and on such a pavement, the only advantage of a transverse slope is to drain shallow depressions due to faulty construction, wear, or a settlement of the foundation, and to aid the rains in washing the pavements. Second, the surface of the pavement has no tendency to wash; and hence the crown need not be increased on a grade as in the case of earth roads. The less the crown the better for the traffic, and the more uniformly will the travel be distributed over the pavement, although a slight crown is inappreciable in either of these respects. Therefore pavements require only crown enough to drain depressions of the surface due to faulty construction, to wear, or to settlement of the foundation; and the crown may decrease as the grade increases.

510. Crown. There has been much discussion as to the best form of the surface of a pavement. Some claim that it should be a continuous curve, while others contend that it should consist of two planes meeting in the center. The curved profile is defective in that it gives too little inclination near the middle, the result being that the pavement wears hollow in the center and permits water to stand there. To overcome this objection some engineers raise the center of the pavement $\frac{1}{2}$ or $\frac{3}{4}$ of an inch above the curved cross section. The objection to the two planes is that the sides wear hollow and hold water. An advantage of the curved profile is that the center of the street, which is the part especially devoted to travel, is nearly flat; while the sides, which have the greater inclination, are occupied by teams standing at the curb. Another advantage of the curved profile is that it gives a deeper gutter, which confines the storm water to a smaller portion of the street and reduces the interference with pedestrian traffic.

It is sometimes claimed that the curved form will support the

greater load, because of its arch action; but the arch action of a pavement is entirely inappreciable, owing to the flatness of the arch, to the imperfect fit of the so-called arch stones, and to the instability of the abutments or curbs.

The surface is usually a continuous curve—generally a parabola. For the methods of staking out each, see § 310 and § 312, pages 200 and 201.

511. The early pavements in this country and at present those in some cities in Europe and South America, slope from both sides towards the center. In this form the most valuable part of the street is devoted to drainage purposes, and it is difficult to carry the water to an intersecting street. The pavements of alleys usually slope to the center. This form is better for alleys than a gutter at each side, since it keeps the storm water from flowing along the side of buildings and possibly interfering with light areas, cellar stairways, etc., and it also carries the water over the sidewalk with less annoyance to pedestrian traffic.

512. When construction begins, it is wise to give the one in charge of the work a drawing somewhat like Fig. 108, showing

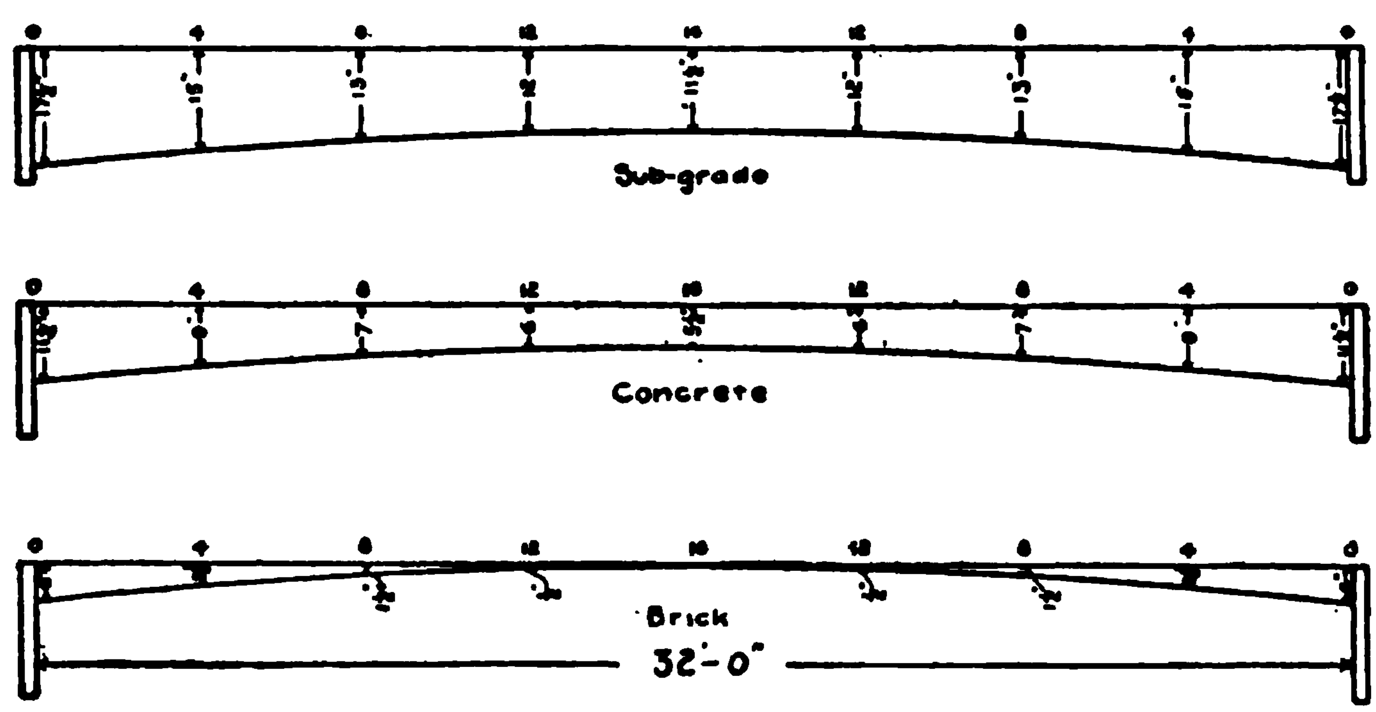


Fig. 108.—Method of Showing Crown of Pavement.

the relation between the top of the curbs and the grade of the foundation, the top of the concrete, and the top of the finished pavement. Such a drawing prevents misunderstandings and disputes. Notice that the curves in Fig. 108 are not exact parabolas, the ordinates at 4 and 12 being $\frac{1}{8}$ inch too long; but this is sufficiently exact, since it is not possible to secure mathematical precision in this class of work.

513. Crown in Various Cities. The following is the practice in different cities. All use the curved profile, and it is immaterial whether it be called a circular or a parabolic arc.

Boston. In Boston * the crown per foot of half width of the pavement is as follows: macadam, $\frac{1}{2}$ inch; granite block, $\frac{3}{8}$ inch; sheet asphalt, asphalt block, or brick, $\frac{5}{16}$ inch. On side-hill streets the maximum difference in elevation between the crown and the pavement next to the curb is as follows: for macadam, $\frac{7}{8}$ inch per foot of the half width of the pavement; for granite block, $\frac{3}{4}$ inch per foot; and for sheet asphalt, asphalt block, or brick, $\frac{6}{16}$ inch. If there are one or more street-car tracks on the street, the above crown is obtained at the rail nearest the curb.

New York. In New York city † the crown for asphalt streets is $\frac{1}{100}$ of the distance between curbs, or say $\frac{1}{4}$ inch per foot of the half width; ‡ and for brick or granite is $\frac{1}{75}$ of the half width or $\frac{3}{8}$ inch per foot.

Chicago. In Chicago § the standard crown for asphalt, brick, or granite block, is a minimum of 2 per cent and a maximum of 5 per cent of the half width; for macadam, a minimum of 4 per cent and a maximum of 8 per cent.

Omaha. In Omaha the crown is decreased as the steepness of the crown increases, a method which is commendable. The crown for asphalt is: ‖ $C = w\ (100 - 4p) \div 5{,}000$, in which C = the crown of the pavement in feet, w = the distance between the curbs in feet, and p = the per cent of the longitudinal grade. For brick, stone block, or wood block, the crown is five sixths of that for asphalt. A formula for crown formerly used in Omaha gave a less crown than the above rule for brick, stone block, and wood block, and as much less crown for asphalt. The former formula is:

for brick, stone block, and wood block, $C = w\ (20 - p) \div 1{,}600$
for sheet asphalt $C = w\ (9 - p) \div 600.$

Notice that in the cities mentioned above asphalt has the smallest crown of any form of pavement, except in Omaha, where

* By authority of William Jackson, City Engineer.

† By authority of E. P. North, Water Purveyor, in charge of pavements.

‡ This is the same crown as that used on the celebrated Alexander Bridge in Paris, France, built in 1899.

§ By authority of J. B. Hittle, Chief Engineer of Streets.

‖ By authority of Andrew Rosewater, City Engineer.

it has the largest. Considering only the smoothness of the surface, it appears that asphalt should have the least crown; but considering only the fact that asphalt rots when continually wet, it appears that asphalt should have a large crown.

514. The above rules for crown must be modified somewhat when the two sides of the street are not at the same elevation—see § 488, page 328.

CHAPTER XI.

CURBS AND GUTTERS.

516. Curb. A curb is a plank or slab of stone set at the edge of the roadway to protect the sidewalk or tree space and to form the side of the gutter. Curbs are not usually set except where the street is paved, but they greatly improve the appearance of an unpaved street and protect the glass plats at the side of the street, particularly during the muddy season.

Curbs are usually formed of natural stone, although concrete curb, usually combined concrete curb and gutter, are increasing very rapidly in recent years—partly because of the decrease in the price of Portland cement. Granite is the best natural stone, but it is usually very expensive. Limestone and sandstone are frequently used, but they are generally too easily chipped or broken. Concrete, unless made with unusual care or protected by steel on the edge, is too friable for a business street where heavy loads frequently back up against the curb.

517. Stone Curb. Granite curb are obtained in large quantities in the localities mentioned in § 813. Hudson River bluestone, a variety of sandstone commercially known as bluestone, is much used for curbs, on account of its hardness, durability, and great transverse strength. It is evenly bedded, and splits with a smooth surface, and is found in large quantities in the counties of the state of New York adjoining the Hudson River from Albany to New York city. A sandstone much used for curbs is quarried in great quantities at Berea, Ohio, near Cleveland. It is generally a uniform gray, but is sometimes spotted with iron stains. It is easily quarried, but is too soft and friable for curbs except on residence streets. Sandstone curbs are also obtained in considerable quantities in the localities mentioned in § 815–20.

518. The thickness should be sufficient to give strength to resist the blows of wheels and to prevent the frost in the earth back of the curb from breaking it off at the top of the gutter. They are 4 to 8 inches thick, usually 4 to 6 inches, depending upon the quality of the stone and the locality. The depth must be sufficient to prevent the thrust of the earth behind the curb from overturning it, and is usually 18 to 24 inches. If the section are too short, it is difficult to keep them in place and the general appearance is not good; and if they are too long, it is difficult to handle and set them, and nearly impossible to get a firm bearing on the bottom. They usually vary from 3 to 8 feet.

The exposed face of the curb should be bush-hammered or axed; and where the sidewalk extends to the curb, the back also should be smoothly dressed so the sidewalk may fit closely against the curb. The upper face should be cut to a slight bevel with the front face, say $\frac{1}{4}$ inch to the foot, so that when the face of the curb is set with a little inclination backward, the top face will be level or slope downward and to the front a trifle. The pavement slopes toward the gutter, and therefore a wagon wheel inclines toward the curb; hence the curb is set leaning back a little to prevent a wheel from striking the face when running at the inner edge of the gutter and also to secure increased stability. The curb is usually cut with a square corner at the outer upper edge; but it would be better if this corner were rounded off slightly, say to a radius equal to one third of the thickness of the curb, to decrease the tendency to chip. The ends of the sections should be smoothly dressed to the exposed depth, and the part not exposed should be knocked off so as to permit the dressed ends to come into close contact. The ends should fit closely for appearance and to prevent the earth, particularly if sand, from running from behind the curb between the sections into the gutter, or to prevent the sand cushion of a brick pavement from running from under the bricks into these cracks and possibly through them into holes behind the curb. In a number of European cities, notably Brussels, the curb is cut with a tongue in one piece which fits into a groove in the next piece, to aid in keeping the curb to line.

The curb should be set with a uniform batter, in a straight line, and on a regular grade. To fulfill these conditions requires careful

work in the first place, and to prevent the curb from subsequently getting displaced requires proper design and thorough workmanship. The trench in which the curb is to be set should be dug 4 to 6 inches below the base of the curb to allow for a layer of gravel on which to set the stone; and the width of the trench should be at least three times the thickness of the curb to allow room for ramming the earth around the stone. The bottom of the trench should be made smooth and be thoroughly consolidated by ramming, and the gravel also should be compacted. Where gravel is expensive, it is dispensed with, the curb being set upon brick or stone. In filling the trench, the earth should be thoroughly rammed in layers not more than 4 inches thick. Where gravel is plentiful, it is sometimes specified that the trench shall be filled with gravel to 8 or 10 inches from the top.

In the past there has been so much trouble in keeping curbs in line, that within recent years there has been a general tendency to set the curb in a bed of concrete—particularly when concrete is used for the foundation of the pavement. A 6-inch layer of concrete is deposited in the trench and the curb set upon it, after which the trench is filled with concrete on the street side up to the base of the proposed pavement and on the back side nearly up to the top of the curb. When set in concrete, the curb does not need to be as deep as otherwise, since the concrete then practically becomes a part of the curb.

519. *Cost.* In most localities, split sandstone or limestone curbing 4 to 5 inches thick can be had for 20 to 25 cents per square foot f. o. b. cars at the destination; and often sawed stone can be had at about the same price. The additional cost of a bush-hammered or axed surface will vary with the hardness of the stone and the degree of the finish, and curves will cost 30 to 50 per cent more than straight pieces. Hudson River bluestone (sandstone) curbing costs from 20 to 40 cents per square foot.

Granite curb costs from 25 to 50 cents per square foot, depending upon locality and thickness.

520. Concrete Curb. In some sections where suitable stone for curbing is not readily available, curbs have been made of Portland-cement concrete. Owing to the decreasing price of cement, this form of curb will doubtless come into more common use. It

is usually made about 6 inches thick and 18 or 20 inches deep. If well made, it does excellently for residence streets.

For suggestions concerning the construction of concrete curb, see § 523–27.

521. Gutters. Incidentally the construction of the gutter has already been considered in § 503–05, which see.

Fig. 109 shows a concrete gutter used in St. Louis, Mo.

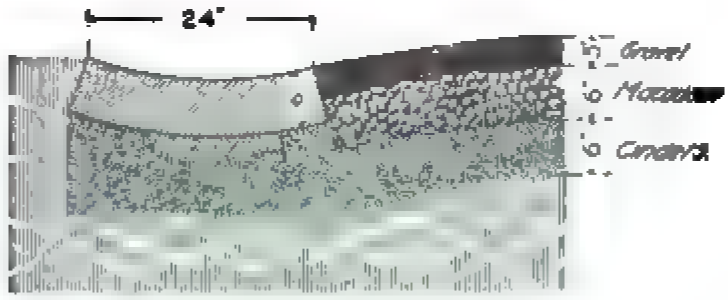


Fig. 109.—St. Louis Concrete Curb and Gutter.

522. Combined Concrete Curb and Gutter. In recent years the construction of combined concrete curb and gutter built in place has become very general in the smaller cities, and in residence districts of larger cities. Such construction is cheap, durable, efficient, and good in appearance. It is very popular with brick pavement, and with asphalt where the grades are very flat, and is often used with a crushed-stone pavement. Fig. 110

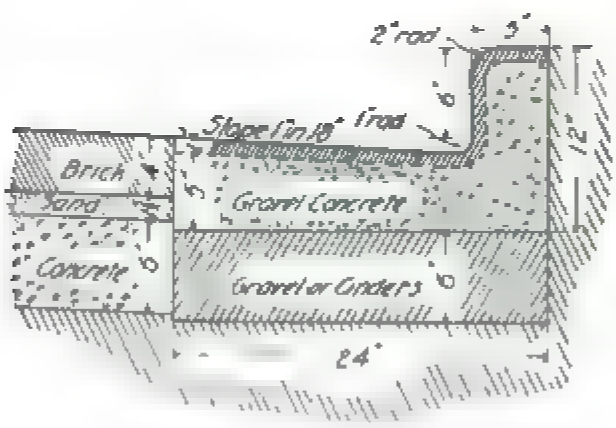


Fig. 110.—Standard Concrete Curb and Gutter.

shows the cross section of the usual form. Fig. 111, page 354, shows the form of combined concrete curb and gutter employed in St. Louis, Mo.

523. Foundation. A trench is excavated 4 to 6 inches wider than the base of the concrete, and a layer of cinders or gravel 4 to 8 inches thick (usually 6 inches) is laid, flooded with water, and

then thoroughly tamped. Upon this foundation is erected the forms in which the concrete is to be laid.

524. The Forms. There are two general methods of constructing these forms: 1. Some contractors lay alternate sections in boxes about 6 feet long, and subsequently place boards against the sections first laid and construct the remaining sections. This plan is more expensive and does not secure as good alignment as

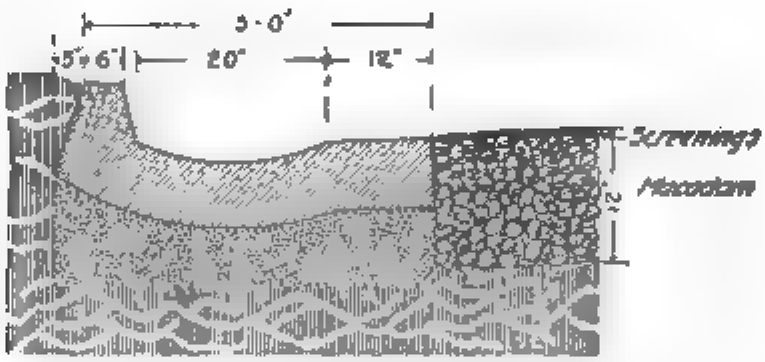


FIG. 111.—ST. LOUIS CONCRETE CURB AND GUTTER.

the method described below. 2. A continuous line of plank is set for the back of the curb and another for the front of the gutter. These plank are kept in place by stakes on both sides. Partitions are inserted so as to divide the mass into sections 6 or 8 feet long.

Two forms of partitions are in common use. Sometimes these partitions are plank $1\frac{1}{2}$ or 2 inches thick, in which case the sections are laid alternately, the partitions being removed before the second series of blocks are formed. In other cases, the partitions are made of steel $\frac{1}{8}$ or $\frac{3}{16}$ inch thick, and are left in position until the blocks are practically finished. There is but little choice between the two forms of partitions, except that it is difficult to withdraw the steel partitions without chipping the surface coat.

525. The form for the front of the curb is made by setting a plank $1\frac{1}{2}$ or 2 inches thick against the front of the upper part of the partitions and clamping it to the plank at the back of the curb with steel screw-clamps. Of course, the lower edge of this plank is rounded to make the curve between the face of the curb and the top of the gutter.

The concrete for the base of the gutter is deposited and tamped, and then the mortar for the face of the gutter is applied—all before the form for the front of the curb is clamped into place. After the plank for the front of the curb is in place, a 1-inch plank is

placed immediately behind it, and the concrete for the body of the curb is deposited and tamped. The 1-inch plank is then carefully removed, and the mortar for the face of the curb is put into the vacant space. Just as the mortar begins to take its initial set, the board in front of the curb is removed, and the curb and the gutter are troweled smooth.

526. Mixing and Laying. The mortar is usually one part of Portland cement to 1½ or 2 parts of clean sharp sand.

The concrete may be made of either gravel or broken stone, the usual proportions being either 1 part Portland cement, 2 parts sand, and 4 parts of unscreened crushed stone, or 1 part cement and 5 or 6 parts of gravel.*

To secure durability it is necessary that the surface layer of mortar should be made with Portland cement; and to secure a good union between the layer of mortar and the concrete, it is necessary that the mortar and the concrete should be made with the same brand of cement. Many attempts have been made to lay a coat of Portland cement mortar upon a natural cement concrete; but nearly always the two have separated. It is also necessary that the mortar coat should be applied as soon as possible after the concrete is laid, so that the cement may set throughout the entire mass at the same time; otherwise there is danger of the two separating. The concrete should be mixed so dry that little or no free water flushes to the surface while it is being tamped. If the water flushes to the top, there will come with it more or less earthy matter which will prevent a firm union of the mortar and the concrete.

The mortar coat should be mixed rather dry; and should be troweled firmly to give a dense surface, but not so persistently as to disturb the initial set.

527. Finishing the Surface. There is a difference of opinion as to whether the surface should be considered finished when it has been troweled, or whether it should be afterwards brushed

* For a full discussion of the method of testing the cement and proportioning the concrete, and of the relative merits of gravel and broken-stone concrete, together with tables of quantities, strength, cost, etc , see A Treatise on Masonry Construction, by Ira O. Baker, pp. 556, 6 × 9 inches. John Wiley & Sons, New York City. 9th edition, 1899.

with a slightly wet brush. An ordinary flat paint brush, with extra heavy bristles, cut off about one inch below the wood portion, may be used for this purpose. The objections to the trowel-finished surface are that the trowel marks show more or less, and that the surface has a glaze or shine clearly indicating that the stone is artificial; while the brush finish has a uniform dull surface similar to a smoothly dressed natural stone. The objections to the brush-finished surface are that the brush leaves a porous surface that is not so durable as a trowel-finished one, which objection has considerable force if the surface is not first thoroughly troweled and if the brush is not used lightly. The less the troweling and the more the brushing, the more rapidly the surface can be finished; and hence it is difficult when brushing is permitted to prevent the slighting of the work. Both methods of finishing are employed by competent engineers.

Recently a method of finishing by drawing a template over the curb and gutter has been introduced. The few trials made seem to show that this method is a little less expensive than finishing with a trowel, and that it gives a better general appearance and a better alignment, particularly at the joints.

528. Cost. The cost will depend somewhat upon the price and the quantity of the labor and materials, but chiefly upon the proportions of the mortar and the concrete. The amount of cement required will vary a little with the per cent of voids in the sand and gravel or broken stone, but will depend chiefly upon the proportions of the mortar and the concrete. On three contracts for a total length of about 2½ miles of the form of combined curb and gutter shown in Fig. 110, page 353, using gravel in the concrete, laid by two separate contractors, the length laid for each barrel of Portland cement was 13.4, 13.44, and 14 feet respectively. A barrel of cement made enough 1 to 1½ mortar for the surface coat on 33 linear feet.

A yard of gravel was required for each 33 lineal feet.

The amount of labor will vary a little with the amount of excavation required and with the kind of forms employed. On two of the contracts referred to above, one contractor averaged 2.25 feet of completed curb and gutter per man per hour, while the other contractor averaged 2.56 feet per man per hour. The latter exca-

vated the trench by hand before the roadway was excavated, while the former excavated the roadway and the gutter with scrapers before commencing the construction of the curb and gutter. The curb was straight and practically continuous. The working force was usually divided about as follows:

1 foreman,
11 men wheeling and tamping cinders,
5 men setting forms,
24 men mixing and laying concrete,
2 men finishing,
3 assistant finishers.

The contract price for the curb and gutter referred to above was 48 cents per lineal foot, including the excavation and the back filling.

529. Double Curb and Gutter. Fig. 112 * shows the form of the concrete double curb and gutter referred to in paragraph 2 of § 488, page 328.

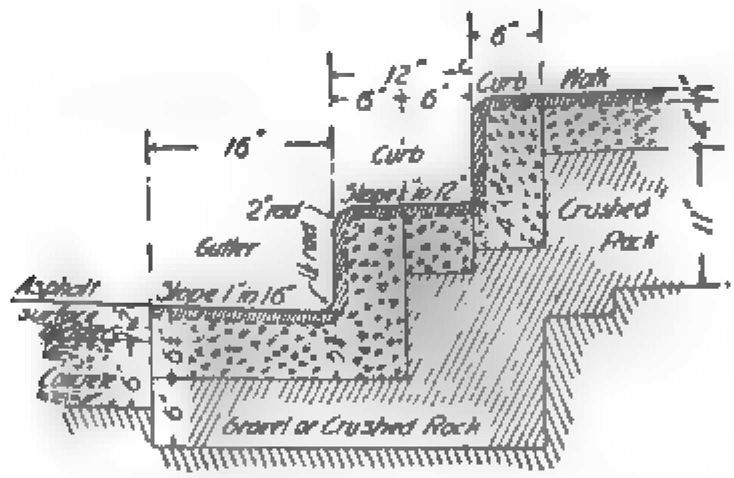


FIG. 112.—DOUBLE CURB AND GUTTER.

530. Curb and Gutter at Private Driveway. Fig. 113, page 358, shows the arrangement of the combined concrete curb and gutter at a driveway to a gate or a building. The radius of the curve at the corner of the curb is too small, as a radius of 4 or 5 feet would be better.

531. Merits of Concrete Curb and Gutter. The advantages of the combined concrete curb and gutter are: 1. It is usually cheaper, particularly if account be taken of the fact that the gutter

* Trans. Amer. Soc. of Civil Engineers, Vol. 42, p. 7.

occupies space that otherwise would be paved. 2. The alignment of the curb is better and more permanent. 3. The appearance is better. 4. Usually the concrete is more durable than a natural stone of equal cost. 5. The gutter is smooth, and easily cleaned.

A concrete curb is suitable only for residence streets, but is more durable for a business street than soft sandstone or limestone.

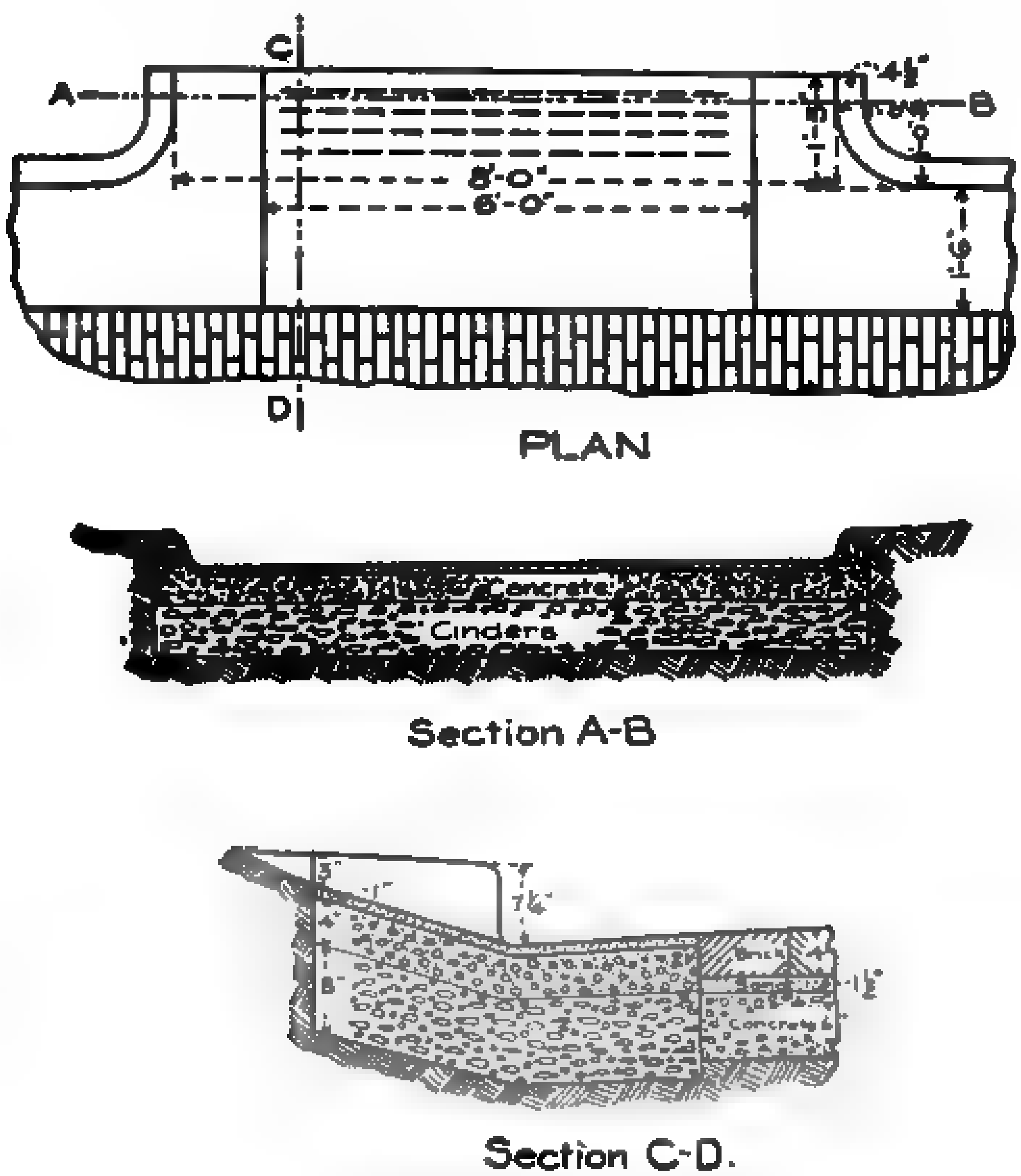


FIG. 118.—CONCRETE CURB AND GUTTER AT PRIVATE DRIVEWAY.

532. OTHER FORMS OF CURB. About 1889 there was constructed on two streets at Washington, D. C., a concrete curb and gutter having at the inner lower edge of the curb a 4×4 inch conduit for telegraph and telephone wires, with hand holes about

50 feet apart.* The experiment was not considered successful, and the conduit was never used for wires.

From time to time advertisements appear of burned clay curbs, but none have been seen which are not so thin as to be easily broken and so constructed by sections fitted together to be unstable.

533. Radius of Curb at Street Corner. As far as vehicular traffic is concerned, the larger the radius of the curb the better; but when the gutter is carried to a corner inlet (§ 499), it is inconvenient to construct or cover the gutter if the curved curb intersects the sidewalk, i. e., if the radius of the curved curb is too great. If the pavement has the minimum width, say 18 or 20 feet, the curves of the corner curbs should be made large so that a vehicle may be turned around at the street intersection. If the curb is stone, the curved sections cost considerably more than straight ones; and consequently the less the amount of curved work, i. e., the shorter the radius, the less the job will cost. With concrete curb the curves cost but little more than straight work.

The radius generally varies from 2 to 12 feet, usually from 6 to 8. The corner with a 2-foot radius can usually be obtained in one piece, and should be used only at driveways to private grounds, at alleys, and on unfrequented streets when the cost of curved work is great and the amount of money available is small. A radius of 8 or 10 feet is very satisfactory. Where the angle is more than 90°, as, for example, at a bend in the street, a still larger radius can be employed.

534. Curb and Gutter at Driveway. Fig. 113 shows the arrangement of the combined concrete curb and gutter at a private driveway. The radius of the face of the curve of the curb as shown is only 1 foot, which is quite commonly used; but the design could be improved by making it at least twice as great.

* For detailed plans, see The Technograph—the annual published by the Association of Engineering Societies of the University of Illinois,—No. 5, p. 32.

CHAPTER XII.

PAVEMENT FOUNDATIONS.

534. The term foundation is sometimes applied to the natural soil upon which an artificial structure rests, and sometimes to the lower portion of the structure itself. The term will be employed here in the latter sense, and the soil under the foundation of the pavement will be referred to as the subgrade. The foundation of a pavement, as of all other structures, is an important element, although it is more frequently neglected in pavements than in other structures.

ART. 1. PREPARATION OF THE SUBGRADE.

535. Whatever the form of the pavement or of its foundation, it must rest upon the soil; and since the chief office of the pavement and of its foundation is to distribute the concentrated load of the wheel over an area so great that the natural soil will be able to support it, it is important to increase, as much as practicable, the bearing power of the soil by drainage and by rolling, and thereby to decrease the thickness of pavement required.

536. DRAINAGE. The method of draining the subgrade of a pavement is substantially the same as that of underdraining an earth road—see § 98. The subgrade of a pavement requires underdrainage fully as much as does an earth road, notwithstanding the fact that the former has an impervious roof. The purpose of the underdrainage is to prevent the surface of saturation from rising so high as to soften the subgrade. Unless the subsoil is very open and porous, it is economical to lay a tile under each edge of the pavement, 2 or 3 feet below the surface of the subgrade. This tile may empty into the surface-water catch basins (§ 497).

537. EARTHWORK. The machinery employed in making excavations and embankments for pavements is practically the same as that used in constructing earth roads—see § 135–44.

In making embankments great care should be taken to compact them solid—see Shrinkage of Earthwork (§ 127), Settlement of Embankments (§ 128), Rolling Embankments (§ 130), and Stability of Embankment (§ 133). For data on the Cost of Earthwork, see § 154–76.

The excavation for pavements is made by plowing and then removing the earth either with a drag or a wheel scraper (§ 141), or by loading it into wagons or carts with shovels. It is usual to specify that no plowing shall be allowed within 2 inches of the subgrade, to prevent the soil below the subgrade from being loosened. If the subgrade is thoroughly rolled, as described later, plowing a little below the finished surface is not a serious matter; but if the subgrade is not subsequently well rolled, the loosening of the soil below the finished surface is very objectionable, since the foundation will then have an uneven hardness.

The subgrade is often finished with pick and shovel, but the work can be done much more economically with the scraping grader (§ 142) or with the surface grader, Fig. 114. The former makes a more uniform surface, and is usually more economical; although the latter is an effective implement. In either case the loosened earth must be hauled away with scrapers or wagons.

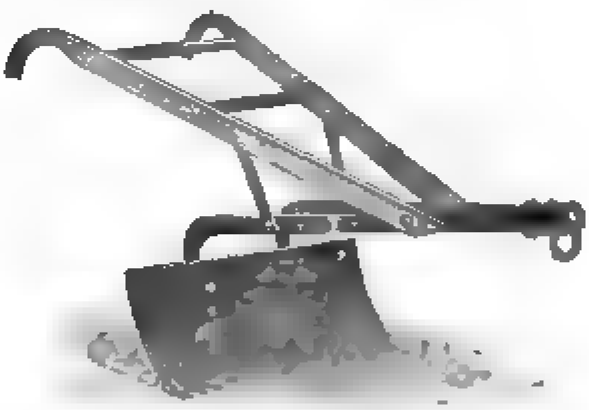


FIG. 114.—SURFACE GRADER.

538 A considerable part of the excavation is often done before the curb is set, but the curb is always set before the subgrade is finished. The exact position of the subgrade is determined by stretching a string transversely across the street from curb to curb and measuring ordinates similar to those shown in the upper diagram of Fig. 108, page 347. Some contractors pick narrow trenches down to the subgrade at short intervals transversely across the street; while others drive stakes with their tops a specified distance, say 4 or 6 inches, above subgrade, and provide the work-

men with a stick of this length with which to measure down from the top of the stake to the subgrade. The former method must be employed when the scraping grader is used. The passage of the grader fills the trench with loose earth, but it is easy to see the relative position of the surface and the bottom of the trench.

539. Rolling the Subgrade. The finished subgrade should be thoroughly rolled to consolidate the surface and also to discover any soft places—particularly over trenches that have not been solidly filled. If the roller reveals a low place, it should be filled with earth and be rolled again. The roller, whatever its weight, should be passed over the subgrade more than once, since the successive passages have something of a kneading action and add to the solidity of the soil. Several passes with a light roller give better results than a few passes with a heavy one. It is well to specify both the weight of the roller and the number of times it is to pass over the road-bed. For some hints applicable in rolling the subgrade, see § 326.

It is customary to use a horse roller (§ 337) for this purpose, but a steam roller (§ 338) is much better because it is heavier, and, still more important, because with it the street can be rolled transversely. The street is full of trenches made often just before the pavement is laid, in connecting the houses with the sewer, the water, and the gas; and as these trenches run both longitudinally and transversely, it is necessary to run the roller in both directions if the trenches are certain to be solidly filled. With a horse roller, it is practically impossible to roll the street transversely, but with a steam roller this is comparatively easy.

Unless the back-filling of a trench has been unusually well tamped, a roller run transversely over a trench will leave a depression. In most soils, the back-filling will not of itself settle into its former solidity, however long it is left to the action of traffic and to the forces of nature; and whatever the foundation of the pavement, the heavier traffic is nearly certain to cause a settlement over these same trenches, unless the subgrade is well rolled. Traffic consolidates only a thin layer near the surface, which is usually removed when the pavement is constructed. Ordinarily, if the subgrade is rolled both longitudinally and trans-

versely with a steam roller weighing 10 or 12 tons, there will be no settlement of the pavement.

In rolling, if a depression is produced over a trench, it should be filled and then again rolled. If the depression is of considerable depth, it shows that the trench was badly filled or was very deep, or both; and therefore it is wise to re-consolidate the trench. One way of doing this is to make numerous openings through the crust and keep the depression filled with water until the earth in the bottom of the trench has become thoroughly soaked; and then after the ground has dried out below, the roller should again be passed over the surface. The surest way to prevent settlement over trenches is to pack the soil solidly when the trench is first filled. For a discussion of various methods of back-filling, see § 540.

Insufficient tamping in filling trenches or inefficient rolling of trenches is a very common defect in pavement construction, nearly every block presenting one or more such depressions. One of the purposes of a guarantee of the pavement (§ 450) is to secure a thorough consolidation of the soil in the trenches.

540. FILLING TRENCHES. The back-filling of trenches opened to lay water and gas pipes, to make house connection to sewers, etc., so that the road surface shall be restored to its former level and remain so, is a matter of importance on both paved and unpaved roads—particularly the former. The failure to re-fill the trenches properly is a source of annoyance to those who use the road and of damage to the pavement itself. It is frequently asserted by those having opportunity for knowing, that the damage to pavements through lack of care in re-filling trenches and re-placing the pavements is greater than the wear due to traffic. No kind of municipal work should be more rigorously inspected than the filling of a trench over which a pavement is to be laid. The nearly universal result of a neglect in this respect is that a pavement built at great expense is disfigured or damaged by settlement, the repair of which will cost many times as much as it would have cost properly to fill the trench originally.

The principal cause of failure is lack of care, but sometimes it is due to a mistake as to the proper method to be employed. A discriminating judgment is required to determine the proper

method, and intelligence and faithfulness are necessary in carrying it out. There are several distinct methods used in consolidating the back-filling of trenches.

541. Natural Settlement. A common practice of those having occasion to make excavations in unpaved streets is to cast back loosely the material taken out, heaping it into an unsightly and annoying ridge over the trench, and trusting to travel and the elements to restore the surface to its original level. In nearly pure sand such a ridge may in time settle to the original level, although the damage due to the temporary ridge will generally be much more than the cost of properly filling the trench in the beginning; but as a rule earth loosely put back will not attain a sufficient degree of compactness to make it a safe support for a macadam or other form of pavement. The surface may become very compact and hard; and yet after the removal of the foot or more of soil, ordinarily necessitated by the construction of the pavement, it will be found that the earth in the trench will settle considerably under a roller run transversely over the trench. Even though the surface may support the roller, it is highly probable that ultimately a trench which has been loosely filled will settle and cause a depression in the pavement. This is proved by the numerous depressions in pavements, and also by the fact that when trenches loosely filled are opened years afterwards, it is very common to find open cavities. The promptness with which natural settlement takes place depends upon the climatic conditions and the underdrainage. It is never safe to depend upon natural settlement to secure the proper compacting of the soil in trenches over which a pavement is to be laid, however long the time allowed for the settlement, and much less the few weeks often specified.

542. Flooding. Where the water can be had cheaply, it is a common practice to attempt to consolidate the earth in the trench by flooding or puddling it. If the soil is sand or gravel and is so pervious that the trench will drain out rapidly, thorough flushing will compact the material so that no trouble will be experienced with settlement; but the flushing must be done thoroughly. It is not sufficient to fill the trench nearly full of loose material, and then turn on a gentle stream of water until the trench is full; for

trenches thus filled are certain to settle later. The sand or gravel should be added in layers not more than 8 or 10 inches thick, and each layer should be flushed with a stream of water having force enough to wash the finer particles into the voids between the larger ones. Substantially the same result may be accomplished by shoveling the sand or gravel into water 8 or 10 inches deep; but this method will not be effective, if the trench is filled with a scraper or a scraping grader.

However, wherever flushing is effective, tamping would be equally as good and would probably be less expensive, if the cost of the water be considered. As a rule attempting to consolidate trenches by flooding is bad practice.

Neither of the preceding methods of using water should be employed with clay or clayey soils, since flushing prevents rather than assists the consolidation of such soils. In other words, flushing or puddling is useful only with soils which water readily breaks down. If clay is flooded or is deposited in water, the trench is filled with a watery mud that will shrink very much as it dries out and will always be loose and porous. It is well known that a stiff-mud brick which has been moulded under exceedingly heavy pressure will shrink in drying 5 per cent, and with some clays 10 per cent; and of course the thin clay mud in a flooded trench will shrink very much more than this.

543. Tamping. Except in the case of comparatively clean sand and gravel, back-filling can be thoroughly done only by tamping; and to make this method successful it is necessary (1) that the material shall be moist enough to be plastic, but neither too wet nor too dry, (2) that it shall be deposited in layers not more than 3 or 4 inches thick, and (3) that each layer shall be thoroughly rolled or tamped. To secure thorough tamping the relative numbers of tampers and shovelers is sometimes specified; but this alone is ineffectual since there is a natural tendency for the tampers to work less energetically than the shovelers, and besides more labor is required to tamp the soil around a pipe than higher up.

The amount of ramming required will vary with the character and condition of the soil. Clay and hard pan should be moistened before being tamped, while clean sand or clean gravel may be tamped

dry. The tamping can be most effectively done with a comparatively small light rammer or tamper, since the effect of the blow is transmitted to a greater depth, while a broad heavy rammer consolidates the surface only. A tamper weighing 5 or 6 pounds is better than one weighing 20 or 25 pounds. the lighter one being lifted higher and giving less fatigue than the heavy one. It is important to remember that any amount of ramming will affect only a comparatively thin layer.

Obviously back-filling should not be attempted when the material is frozen, since subsequent settlement is then sure to take place.

544. To prevent disturbing the surface of a pavement, plumbers, gas fitters, etc., are sometimes given permission to tunnel under the pavement to make their connections. This practice is never justifiable on account both of the excessive cost and of the impossibility of effectively filling the tunnel, owing to the limited space in which the work must be done. In nearly every case a depression occurs sooner or later over the tunnel

545. Replacing All the Material. The result to be obtained in filling a trench is that the material in the trench shall have the same compactness as the soil around it; and therefore some contend that the only proper way is to put back all the material taken out. In a majority of cases, this procedure will secure reasonably good results; but under certain conditions it will fail. For example, the water pipe or sewer may occupy a large proportion of the volume of the trench, and consequently of necessity there will be a considerable excess of earth. Again, putting back all the earth does not insure the restoration of the original surface nor certainly prevent subsequent settlement. It has been shown that soil when taken from its natural place and compacted in an embankment will shrink from 8 to 15 per cent (see § 127), and will probably subsequently settle 2 or 3 per cent and possibly 10 to 25 per cent (see § 128). Consequently with a deep trench containing a small pipe, it is possible to tamp the earth back so solidly as not to have enough to restore the surface; or it is possible to put all the soil back by tamping the lower portion of the trench solidly and the upper portion loosely, and still considerable settlement take place. Therefore the specification to re-place all

of the material, must have a careful and intelligent supervision to insure good results.

In the past it has not been the custom to fill trenches in such a manner as to prevent settlement; and therefore if the best results are to be insisted upon, the specifications should clearly reveal that fact, for contractors in bidding on work do so on the understanding that the work is to be done in at least approximately the usual manner, and any attempt to have it done in any better way, which was not clearly understood from the beginning, is likely to cause friction and irritation, and possibly finally to result in failure.

546. Re-filling with Sand or Concrete. On account of the difficulty of getting trenches in clay or loam filled so that there will be no settlement, it has been proposed to require the trench to be filled with clean sand or gravel. It is not known that this method has ever been tried. It would probably be effective, but usually its cost would be prohibitive.

In at least a few cases trenches have been filled with a fair quality of natural cement concrete. The expense for the concrete was not justifiable, since it was much greater than that required thoroughly to tamp the back-filling.

Sometimes municipal authorities are lax in inspecting the filling of trenches, owing to the belief that the concrete foundation will hold up the pavement even though the material in the trench may settle; but this is bad practice, since the ordinary thickness of concrete is not designed to act as a bridge, and besides if it is thick enough to bear up over trenches it is needlessly thick elsewhere. With the usual thickness of concrete foundations, a depression is almost certain to occur if the material in the trench settles; and hence the only safe rule is to have the trenches completely and compactly filled.

ART. 2. CONCRETE FOUNDATION.

547. This form of foundation consists of a layer of hydraulic cement concrete; it is absolutely necessary for a sheet asphalt pavement, and is frequently used with wood, brick, and stone-block pavements. Concrete foundations are much more common

now than a few years ago, doubtless partly because of the less cost of hydraulic cement.

The author's Treatise on Masonry Construction * devotes 110 pages to cement, sand, gravel, broken stone, and concrete; and therefore the materials will not be discussed here, and the methods of mixing and placing the concrete will be considered only as far as they are dependent upon the particular use to which the concrete is put. The above volume contains detailed explanations of the methods to be used in testing the materials of concrete, discusses the theory of proportioning, and also presents numerous tables showing the strength and cost of various grades of concrete.

548. ADVANTAGES OF CONCRETE FOUNDATION. The advantages of concrete for a pavement foundation are: 1. It gives a smooth uniform surface upon which to lay the pavement. 2. It prevents the surface water from percolating to the subgrade. 3. By its thickness and resistance to flexure, it distributes the concentrated load over a considerable area of the subgrade. 4. Concrete acts as a bridge to support the pavement in case of a settlement of the subgrade. 5. Being impervious to water and a non-conductor of heat, concrete protects water and gas pipes from freezing.

549. THEORY OF CONCRETE. To secure the greatest strength at the least cost, the proportions of the concrete should be so adjusted that the voids in the sand will be filled with cement paste, and the voids in the gravel or broken stone will be filled with cement mortar. The cement is the most expensive ingredient; and if more cement or more mortar is used than is required to fill the voids, the cost is needlessly great. Again, the cement is usually the weakest ingredient; and hence if more of it is used than is necessary, the strength of the concrete is thereby decreased. Table 34 and 35, pages 370–71, from the author's Treatise on Masonry Construction, give the amount of voids in sand, gravel, and broken stone.

In a perfect concrete, every sand grain will be coated with cement paste, and every point of each fragment of broken stone will be covered with cement mortar. The coating of cement

* A Treatise on Masonry Construction, by Ira O. Baker. 556 pages, 6 × 9 inches. John Wiley & Sons, New York City. Ninth Edition, 1899.

paste on the sand grains and of mortar on the fragments of stone holds the several pieces apart, and increases the voids; and consequently it is not possible to determine by computation the amount of cement paste or cement mortar required to fill the voids of any grade of broken stone. The exact proportions required in any particular case can be determined only by trial. The data in Table 36 and 37, pages 372–73, from the author's Treatise on Masonry Construction, were derived from experiments, and are sufficiently exact for practial use. These tables give proportion in which the voids are just filled when the mortar or concrete is compacted; and are very useful in making estimates.

In the method of proportioning implied in Table 36 and 37, the amount of cement or mortar will be stated in per cent of the volume of the sand or the stone depending upon the proportion of the voids; but not infrequently the proportions of the concrete are stated by volumes independently of the proportion of the voids in either the sand or the broken stone, in which case Table 38, page 374, will be useful in making estimates. For a discussion of the disadvantages of the latter method of proportioning, see pages 112*d*–112*f* of the author's Treatise on Masonry Construction.

550. Data for Estimates. Table 34 and 35, pages 370 and 371, give the quantities of cement, sand, and broken stone required to make a cubic yard of concrete, the first when the proportions of the ingredients are fixed with reference to the voids in the sand and stone, and the second when they are fixed arbitrarily. Each table gives the quantities for unscreened and also for screened broken stone; and Table 34 gives also the quantities of cement and gravel required for a cubic yard of gravel concrete. The barrel of cement in both tables is the commercial barrel of packed cement.

Table 34 is recommended for general use, since the proportions are more scientific and more economical. The first line gives a concrete of the maximum density and maximum strength, i. e., the quantity of mortar is sufficient to fill the voids; and the successive lines give concretes of decreasing density and strength. The third and subsequent lines give concretes containing mortar equal to the voids, the mortar in the third line being 1 to 3, in the fourth 1 to 4, etc.

TABLE 34.

FINENESS, VOIDS, AND WEIGHT OF SANDS FOR MORTAR.

Arranged in order of Per Cent. of Voids.

Ref. No.	Description.	Fineness. Per Cent., by weight, caught on Sieve No. 5	20	30	50	75	Per Cent passing No. 75.	Voids, Per Cent. of the Volume. Dry and Loose.	Saturated and Rammed	Weight, Lbs. per cu. ft. Dry and Loose.	Dry and Well shaken.
1	Crushed quartz	0	0	99	1	0	0	55	43	81	88
2	Crushed granite	0	0	100	0	0	0	54	41	80	87
3	Crushed limestone (flinty)	0	0	100	0	0	0	53	41	88	91
4	German standard sand	0	0	99	1	0	0	41	38	91	104
5	Bibbus's sand, Urbana, Ill., sifted	0	100	0	0	0	0	46	37.8	91	99
6	" " " "	0	0	100	0	0	0	45	38.4	88	97
7	" " " "	0	0	0	100	0	0	44	36.0	85	96
8	" " " "	0	0	0	0	100	0	45	35.7	86	97
9	" " " "	0	0	0	0	0	100	47	33.8	88	96
10	" " " unsifted	0	27	31	23	9	10	41	30.0	91	100
11	Sand from cement walk, Champaign, Ill.	0	13	17	24	39	5	44	36	89	97
12	"Torpedo sand," Chicago	0	41	19	18	18	3	45	37	101	113
13	Sand from municipal work, Illinois	0	4	1	2	12	81	37*		....	96
14	Sand much used in Chicago	0	3	1	3	24	67	37*		....	98
15	Sand from municipal work, Chicago	0	27	19	32	14	8	33*		....	106
16	Crushed limestone (flinty)	0	60	13	7	5	15	32*		....	110
17	Crushed granite	0	56	12	11	8	13	30*		....	113
18	Sand artificially mixed	0	33†	12½	12½	12½	25‡	23*		....	123

* Dry and well shaken. † 12½% on No. 10; 12½% on No. 15; 12½% on No. 20. ‡ 12½% passing No. 100.

TABLE 35.
VOIDS AND WEIGHT OF GRAVEL AND BROKEN STONE FOR CONCRETE.
Arranged in the order of the Voids.

Ref. No.	Material.	Fineness.									Voids, per cent. of Volume.		Weights, Lbs. per cu. ft.	
		Per cent. by weight not passing ring having diameter of			Per cent. by weight on Sieve No.*					Per cent. passing Sieve No. 75.	Loose.	Rammed.	Loose.	Rammed.
		2″	1″	½″	5	20	30	50	75					
1	Flint (screened)........	0	100	0	......	......	......	......	......	....	53	49	77	79
2	" "	33	33	33	0	......	......	......	......	....	48	43	86	89
3	" "	0	25	75	0	......	......	......	......	....	49	39	85	101
4	Granite (screened).....	....	0	100	0	......	......	......	......	....	48	44	83	86
5	" "	....	....	0	100	0	......	......	......	....	48	44	84	87
6	" "	....	0	84	16	0	......	......	......	....	44	39	92	94
7	" (crusher run)..	0	27	32	21	9	4	3	2	2	35	30	104	112
8	Limestone (screened)..	0	100	....	......	......	......	......	......	....	51	45	84	95
9	" " ..	....	....	0	100	0	......	......	......	....	45	38	93	105
10	" " ..	0	30	....	51	19	0	......	......	....	33	28	110	118
11	" (crusher run).	4	23	24	17	19	4	2	1	5	32	27	112	121
12	Pebbles (screened)....	0	100	0	......	......	......	......	......	....	45	42	82	90
13	" "	....	0	20	80	0	......	......	......	....	44	39	84	92
14	" "	....	....	0	100	0	......	......	......	....	44	40	90	97
15	" "	0	26	14	60	0	......	......	......	....	41	37	100	117
16	Gravel (screened).....	0	16	9	36	39	0	......	......	....	37	32	115	124
17	" (unscreened)...	0	10	7	24	34	10	5	7	1	34	27	120	131
18	" " ...	0	11	6	18	33	7	9	15	1	30	20	125	145

* The diameter of the meshes is as follows: No. 5, 0.18″; No. 20, 0.032″; No. 30, 0.022″; No. 50, 0.012″; No. 75, 0.007″.

TABLE 86.

CEMENT AND SAND REQUIRED FOR 1 CUBIC YARD OF MORTAR.

Parts of Sand to 1 Part of Cement.	Mortar proportioned by weight.					Mortar proportioned by volumes of *packed* cement and loose sand.					Mortar proportioned by volumes of *loose* cement and loose sand.				
	Portland.		Natural.			Portland.		Natural.			Portland.		Natural.		
	Cement, *bbl.*	Sand cu. yd.	Western, *bbl.*	Eastern, *bbl*	Sand, cu. yd.	Cement, *bbl.*	Sand, *cu. yd.*	Western, *bbl.*	Eastern, *bbl.*	Sand, *cu. yd.*	Cement, *bbl.*	Sand, *cu. yd.*	Western, *bbl.*	Eastern, *bbl.*	Sand, *cu yd.*
0	7.40	0.00	8.40	7.42	0.00	7.40	0.00	8.40	7.42	0.00	7.40	0.00	8.40	6.81	0.00
1	4.05	0.57	5.23	4.62	0.51	4.17	0.57	4.87	4.29	0.58	3.87	0.63	4.66	4.11	0.60
2	2.80	0.78	3.65	3.22	0.72	2.91	0.78	3.24	2.85	0.76	2.42	0.81	2.97	2.61	0.78
3	2.00	0.85	2.70	2.38	0.80	2.06	0.85	2.38	2.10	0.81	1.73	0.88	2.12	1 87	0.84
4	1.60	0.89	2.17	1.91	0.84	1.66	0.89	1.80	1.59	0.86	1.35	0.91	1.64	1.45	0.87
5	1.30	0.91	1.74	1.54	0.86	1.35	0.91	1.48	1.31	0.88	1.10	0.93	1.22	1.07	0.89
6	1.10	0.93	1.48	1.31	0.88	1.14	0.93	1.38	1.21	0.89	1.00	0.94	1.17	1.02	0.90

TABLE 37.

INGREDIENTS REQUIRED FOR A CUBIC YARD OF RAMMED CONCRETE.

Concrete proportional with reference to the Voids.

Ref. No.	UNSCREENED BROKEN STONE.—No. 10, page 80.					SCREENED BROKEN STONE.—No. 6, page 80.					GRAVEL.—No. 17, page 80.			
	Cement.			Sand, loose.	Stone, loose.	Cement.			Sand, loose.	Stone, loose.	Cement.			Gravel, loose.
	Portland	Natural.				Portland	Natural.				Portland	Natural.		
		Western.	Eastern.				Western.	Eastern				Western	Eastern	
	bbl.	*bbl.*	*bbl.*	*cu. yd.*	*cu. yd*	*bbl.*	*bbl.*	*bbl.*	*cu. yd*	*cu. yd.*	*bbl.*	*bbl.*	*bbl.*	*cu. yd.*
1	0.94	1.07	0.94	0.31	0.98	1.25	1.48	1.26	0.42	0.97	1.10	1.23	1.06	0.96
2	0.75	0.87	0.77	0.29	0.96	1.07	1.22	1.08	0.39	0.98	0.84	0.97	0.86	0.95
3	0.58	0.67	0.59	0.24	0.98	0.89	1.02	0.90	0.36	0.99	0.67	0.76	0.67	0.97
4	0.46	0.50	0.44	0.25	0.98	0.71	0.77	0.68	0.37	0.99	0.53	0.58	0.51	0.97
5	0.38	0.41	0.36	0.26	0.98	0.58	0.64	0.57	0.38	0.99	0.43	0.47	0.42	0.96
6	0.36	0.39	0.34	0.27	0.98	0.49	0.59	0.53	0.39	0.99	0.36	0.44	0.39	0.96

TABLE 38.

INGREDIENTS REQUIRED FOR A CUBIC YARD OF RAMMED CONCRETE.

Concrete proportioned without reference to the Voids.

Ref. No.	Proportions by Volumes Loose.			2" to 0".02 Broken Stone.							2" to 1" Broken Stone.						
				Portland Cement.			Natural Cement.				Portland Cement.			Natural Cement.			
	Cem.	Sand.	Stone.	Cem.	Sand.	Stone.	West.	East.	Sand.	Stone.	Cem.	Sand.	Stone.	West.	East.	Sand.	Stone.
				bbl.	*cu. yd.*	*cu. yd.*	*bbl.*	*bbl.*	*cu. yd.*	*cu. yd.*	*bbl.*	*cu. yd.*	*cu. yd*	*bbl.*	*bbl.*	*cu. yd.*	*cu. yd.*
1	1	2	4	1.18	0.38	0.76	1.29	1.14	0.42	0.84	1.34	0.43	0.87	1.48	1.30	0.48	0.96
2			5	1.03	0.33	0.83	1.11	0.97	0.36	0.90	1.18	0.38	0.96	1.22	1.07	0.40	0.99
3			6	0.92	0.30	0.90	0.97	0.85	0.31	0.94	1.02	0.33	1.00	1.03	0.90	0.34	1.01
4	1	3	6	0.81	0.39	0.78	0.89	0.78	0.43	0.87	0.93	0.45	0.90	1.00	0.88	0.49	0.98
5			7	0.74	0.36	0.85	0.80	0.70	0.39	0.91	0.84	0.41	0.96	0.87	0.77	0.42	0.99
6			8	0.68	0.34	0.88	0.74	0.65	0.36	0.99	0.74	0.36	0.97	0.77	0.68	0.38	1.00
7	1	4	8	0.55	0.36	0.72	0.66	0.58	0.43	0.86	0.62	0.40	0.80	0.74	0.65	0.48	0.97
8			9	0.52	0.34	0.76	0.62	0.55	0.40	0.91	0.58	0.37	0.84	0.68	0.60	0.44	0.99
9			10	0.49	0.32	0.79	0.58	0.51	0.37	0.94	0.58	0.37	0.93	0.62	0.58	0.40	1.00

The proportions of the concretes can be determined by remembering that a barrel of cement is equal to 0.13 cu.yd. For example, in the first line of Table 34 for unscreened broken stone and Portland cement, the 0.94 bbl. of cement is equal to 0.12 cu. yd.; and the proportions are: 1 volume of packed cement, 2.5 volumes of loose sand, and 7.5 volumes of loose unscreened broken stone. If it be assumed that a barrel of packed cement will make 1.25 barrels when measured loose, the above proportions become: 1 volume loose cement, 2.0 volumes loose sand, and 6.0 volumes loose unscreened broken stone.

551. Screened vs. Unscreened Stone. It is sometimes specified that the broken stone to be used in making concrete shall be screened to practically a uniform size; but this method is unwise for three reasons: 1. With graded sizes the smaller pieces fit into the spaces between the larger, and consequently less mortar is required to fill the spaces between the fragments. Therefore the unscreened stone is more economical than the screened. 2. A concrete containing the smaller fragments of stone is stronger than though they were replaced with cement and sand.* 3. A single size of broken stone has a greater tendency to form arches while being rammed into place, than the stone of graded sizes. In short, screening the stone to nearly one size is not only a needless expense, but is also a positive detriment.

The dust should be removed, since it has no strength of itself and adds greatly to the surface to be coated, and also prevents the contact of the cement and the body of the broken stone. Particles of the size of sand grains may be allowed to remain if not too fine nor in excess.

552. Portland vs. Natural Cement. It is sometimes a question whether Portland or natural cement should be used. As a rule this question should be decided upon economical grounds, which makes it a question of relative strength and relative price. Formerly prices were such that natural cement was a trifle the cheaper per unit of strength;† but at present prices Portland is usually the cheaper.

* Annual Report of Chief of Engineers, U. S. A., 1893. Part 3, p. 3,015: do. 1894. Part 4, p. 2,321; do. 1895, Part 4, p. 2,953; Jour. West. Soc. of Eng'rs, Vol. II. p. 394 and 400.

† Baker's Masonry Construction. 9th edition. p. 96–99.

553. Gravel vs. Broken-Stone Concrete. There has been much debate as to the relative merits of gravel and broken stone as the aggregate for concrete; but at the same price per unit of volume, broken stone is the better. The reasons for this are: 1. The cement adheres more closely to the rough surfaces of the angular fragments of broken stone than to the smooth surface of the rounded pebbles. 2. The resistance of concrete to crushing is due partly to the frictional resistance of one piece of aggregate to moving on another; and consequently broken stone makes a stronger concrete than gravel. Experiments show that concrete made with gravel is only 70 to 90 per cent as strong as that made of broken stone.*

554. Wet vs. Dry Concrete. There is considerable diversity of opinion among engineers as to the amount of water to be used in making concrete. According to one extreme, the amount of water should be such that the concrete will quake when tamped; or in other words, it should have the consistency of liver or jelly. According to the other extreme, the concrete should be mixed so dry that when thoroughly tamped moisture just flushes to the surface. The advocates of a wet mixture claim that it makes the stronger and more dense concrete; while the advocates of a dry mixture claim the opposite. The difference in practice is not as great as in theory, the apparent conflict being chiefly due to differences in condition.

It is unquestionably true that dry mixtures of neat cement, and also of cement and sand. are stronger than wet mixtures, provided the amount of water is sufficient for the crystallization of the cement. It is also certainly true that in even a dry mortar or concrete, the water is considerably in excess of that necessary for the crystallization of the cement, this excess increasing with the amount of sand and aggregate. Of course an excess of water is an element of weakness. But the amount of water to be used in making concrete is usually a question of expediency and cost, and not a question of the greatest attainable strength, regardless of expense.

In using concrete for pavement foundations the following items

* Baker's Masonry Construction, 9th edition, p. 109.

are worthy of consideration: 1. Wet concrete contains a great number of invisible pores, while dry concrete is likely to contain a considerable number of visible voids; and for this reason there is liability that wet concrete will be pronounced the more dense, even though both have the same density. 2. Wet concrete is more easily mixed; and therefore if the concrete is mixed by hand and the supervision is insufficient or the labor is careless, or if the machine by which it is mixed is inefficient, wet mixtures are to be preferred. 3. Wet mixtures can be compacted into place with less effort than dry; but on the other hand the excess of water makes the mass more porous than though the concrete had been mixed dry and thoroughly compacted by ramming. Dry concrete must be compacted by ramming, or it will be weak and porous; but if the concrete is mixed wet the stones by their weight will bury themselves in the mortar, and the mortar by its fluidity will flow into the voids. 4. A rich concrete can be compacted much easier than a lean one, owing to the lubricating effect of the mortar, and hence a rich concrete can be mixed dryer than lean ones. The quaking of concrete frequently is due more to an excess of mortar than to an excess of water. 5. Lean concretes should be mixed dry, since if wet the cement will find its way to the bottom of the layer and destroy the uniformity of the mixture. 6. Machine-made concrete may be mixed dryer than hand-made, owing to the more thorough incorporation of the ingredients. 7. Gravel concrete can be more easily compacted than broken stone, and hence may be mixed dryer. 8. In mixing dry by hand there is a tendency for the cement to ball up, or to form nodules of neat cement, while in mixing wet this does not occur.

The conclusion is that sometimes wet concrete must be used regardless of any question of strength and cost; while with thorough mixing and vigorous ramming, dry concrete is strongest but also most expensive to mix and lay.

555. Proportions. The usual proportions of concrete employed for foundations of pavements are: with *natural cement*, 1 part cement, 2 parts sand, and 3 to 5, usually 4, parts broken stone or gravel; and for *Portland cement*, 1 part cement, 2 or 3 parts sand, and 5 to 8 parts, usually 5 or 6, of broken stone.

The proportions of the concrete in a measure depend upon the

thickness of the foundation. The purpose of the foundation is to distribute the concentrated pressure of the wheel over an area of the subgrade so great that the soil can support the load; and this distribution can be obtained by varying either the strength or the thickness of the concrete. Therefore the engineer may use a thin bed of rich concrete or a thick bed of lean concrete. The combination to be used in any particular case will depend upon the relative strength of the different grades of concrete and upon the prices of the several imgredients. In some cases it may be economical to use a thicker layer of broken stone without any cement at all (see § 562). However, if a layer of broken stone is employed for a pavement foundation, it should be compacted by rolling until the fragments do not move under the foot in walking over it.

556. THICKNESS. The thickness of the concrete foundation for light traffic is nearly always 6 inches, and for very heavy traffic 8 inches.

557. MIXING THE CONCRETE. The value of the concrete depends greatly upon the thoroughness of the mixing. Every grain of sand and every fragment of aggregate should have cement adhering to every point of its surface. Thorough mixing should cause the cement not only to adhere to all the surfaces, but should force it into intimate contact at every point. It is possible to increase the strength of really good concrete 100 per cent by prolonged trituration and rubbing together of its constituents. The longer and the more thorough the mixing the better, provided the time of mixing does not trench upon the time of set, or the working does not break and pulverize the angles of the stone. Further, uniformity of mixture is as important as intimacy of contact between the ingredients. Of course thoroughness of mixing adds to the cost, and it may be wiser to use more cement or more concrete, and less labor.

Concrete may be mixed by hand or by machinery The latter is usually the better method; since the work is more thoroughly and more quickly done, and since ordinarily the ingredients are brought into more intimate contact But the concrete employed for pavement foundations is usually mixed by hand, apparently because either of the expense of transporting the concrete considerable distances, or of the difficulty of continually moving the

mixing machine. However, several machines have been introduced very recently which give promise of success in mixing concrete for pavement foundations.

The concrete is usually mixed on a board platform 8 or 10 feet square, although a metal plate, $\frac{3}{16}$ to $\frac{3}{8}$ inch thick, possesses some decided advantages. It lasts longer, is easier to shovel from and to wheel upon. The ingredients of the concrete are stored on the parking or in the space to be paved. If the materials are hauled upon the subgrade after it is finished, it will usually be necessary to cover the trackway with plank to prevent cutting up the subgrade. The materials of the concrete are wheeled upon the mixing board, mixed, and cast with shovels directly into place.

The mixing is usually done about as follows: The sand to be mixed in a batch of mortar is spread evenly over the middle of the mixing board, and the dry cement is spread evenly over the sand, then the two are thoroughly mixed with hoes or shovels. As the mixing proceeds the necessary water is added, preferably with a spray to secure greater uniformity and to prevent the washing away of the cement. The mass should be worked until it is of a uniform consistency. The broken stone, having previously been sprinkled but having no free water in the heap, is next added. The whole is then turned until every fragment is covered with cement.

Some contractors use shovels instead of hoes, claiming that the former are more economical. The effectiveness of the shovel varies greatly with the manner of using it. It is not sufficient simply to turn the mass; but the sand and cement should be allowed to run off from the blade in such a manner as thoroughly to mix them. It is difficult to get laborers to do this with the shovel, which is one reason why many contractors prefer hoes. When it is supposed the mixing will be done with shovels, the number of times the material shall be turned is specified; but the specification is not definite, since so much depends upon the manner of doing the work. Often it is specified that the sand and cement shall be turned twice, and that the mortar and stone shall be turned four times exclusive of casting into place. The concrete appears wetter each time it is turned, and should appear too dry until the very last.

558. LAYING THE CONCRETE. After being mixed the concrete is shoveled from the boards into place. The proper thickness of the

layer is indicated either (1) by the tops of small stakes driven at intervals of 4 or 5 feet each way, whose position is determined by measuring down from a string stretched from curb to curb (see Fig. 108, page 347), or (2) by a curved template having one end upon the curb and the other end upon the opposite curb or upon a scantling near the middle of the street. The concrete is brought to the proper elevation with a shovel or a rake, and then tamped.

The rammer usually employed consists of a block of iron or a stick of wood 6 to 8 inches square, weighing from 20 to 40 pounds. The concrete should be tamped until mortar flushes to the top, which secures a smooth surface and guarantees that the mass has been thoroughly consolidated. There are two tricks sometimes employed to make it appear that this condition has been fulfilled. One is to scrape off the mortar left adhering to the mixing board and throw it on top of the concrete already in place. The other is to shovel the concrete up higher than the finished surface and then bring it down with a rake, the stones being pulled out and the mortar left on top. Of course neither of these tricks should be accepted as a substitute for the proper amount of tamping.

Not infrequently loose fragments of stone are left upon the top of the foundation. If the concrete is well mixed and well tamped, there will be no pieces left on its surface; and if they are left there, they should be carefully picked off, since otherwise the paving-blocks will not have a firm even bearing on the concrete. In England the top of the concrete is floated with a thin film of either neat cement or rich mortar to secure a perfectly smooth surface upon which to place the wood paving-blocks.

When finally completed the concrete should be covered with sand, say an inch deep, to keep it from drying out. If the water is evaporated instead of uniting with the cement, the concrete will be materially weakened; concrete stored in a steam-heated room will attain to only about half the strength of cubes stored in water. Therefore if the weather is warm and dry, the sand covering the concrete should be sprinkled at intervals to keep it damp. No teaming or walking on the concrete should be permitted until it has firmly set—which is usually assumed to require from 4 to 10 days, depending on the activity of the hydraulic cement used. With reasonable care and ordinary cement, the pavement may be laid

four or five days after the concrete is placed, although many engineers to be on the safe side wait 8 or 10 days. The fact that the street is closed for a considerable time to allow the concrete to set, is the only objection, except possibly the cost, to this form of foundation.

559. COST OF CONCRETE. The cost of the materials varies with the locality and the conditions of the markets; and hence it is unwise to cite examples or to attempt any generalizations. When the prices are known estimates may be easily prepared by the use of Tables 36 and 37 or 38. pages 372, 373, 374.

560. For detailed data on the cost of mixing and laying concrete in miscellaneous engineering construction, see the author's Treatise on Masonry Construction, pages 112*v*–112*z*. The following relate to the cost of mixing and laying concrete for pavement foundations

In a small western city the average cost to the contractor of mixing and laying a thickness of 6 inches of concrete during two years was about 7 cents per square yard, for 1 part cement, 2 parts sand, and 4 parts broken stone, turned six times exclusive of casting into place. With gravel instead of broken stone, the cost was about 6 cents per square yard; and with four turnings instead of six, the cost was about half a cent less than the prices above. All the mixing was done with shovels. The wages of common laborers was $1.50 for 10 hours.

In a large western city the average cost to various contractors of mixing and laying a thickness of 6 inches of concrete was 5½ cents per square yard. The mixing was done with hoes, the specifications requiring that the concrete should be mixed until each particle of the stone was completely covered with mortar. The wages of common laborers was $1.50 for 10 hours.

The following example * gives the detailed cost and distribution of the labor of laying a 6-inch concrete pavement foundation, in hours per square yard.

4 men filling barrows with sand and stone	0.15
10 men wheeling, mixing, and shoveling to place (3 or 4 steps)	0.37
2 men ramming	0.07
1 water boy	0.01
1 foreman	0.06
Total, hours per sq yd	0.67

* *Engineering News*, Vol. 46, p. 424—Dec. 5, 1901.

The sand and stone were dumped in the street upon boards, and were hauled in wheel-barrows about 40 feet to the mixing boards. The mortar was turned three, and the stone three or four times. Two gangs under separate foremen worked side by side in the same street.

The same correspondent gives another example which required 0.57 hours per cu. yd., in which case the mortar was turned only once and the stone twice, water being used in abundance.

The cost of labor in mixing and laying concrete is often 8 or 9 cents a square yard. For the most economical work the sand and stone should be deposited in ridges on the subgrade near the middle of the street; and if they are piled on the parking, the cost will be considerably greater than above.

561. Portable concrete-mixing machines have been tried for pavement foundations, but have not been very successful. Apparently the hand labor required with the machine is about equivalent to that required to mix the concrete by hand directly; in other words, the cost of shoveling the ingredients from the ground up and into the machine is about equivalent to the cost of mixing by hand. Of course, with a machine, interest and depreciation will amount to considerable particularly as the machine will probably be in use only a comparatively few days during the year. However, two or three concrete-mixing machines have recently been introduced which give promise of success for pavement work.

ART. 3. MISCELLANEOUS FOUNDATIONS.

562. MACADAM. Where crushed stone is especially plentiful or cement is unusually expensive, a thick course of macadam may be more economical than a thin layer of concrete Concrete distributes the concentrated load of the wheel over a considerable area of the subgrade by virtue of both its thickness and its transverse strength; while macadam distributes the pressure only by virtue of its thickness. Therefore if the cement is omitted the thickness of the broken stone should be increased. The efficiency of a layer of broken stone in distributing the concentrated load on a wheel is proved by the fact that under very favorable circumstances 4 inches of macadam has successfully carried a considerable traffic (§ 321),

while 6 inches of macadam are quite common (§ 320). If 4 or 6 inches of macadam without any other pavement will carry the traffic, the same thickness will certainly make a good foundation for a pavement of brick, or wood, or stone blocks.

A macadam foundation should be laid substantially as the lower course of a macadam road (§ 339). The rolling should be continued until the stones are firm under foot as one walks over the layer. If the stone is soft (there is no objection to a moderately soft stone for this purpose), the rolling will crush the top of the layer to such an extent that the surface will be nearly impervious. If the wearing surface of the pavement is not too impervious, or if the drainage of the subsoil is not good, or if for any other reason it is desired to make the foundation impervious, it may be done by spreading stone dust upon the rolled macadam and continuing the rolling with or without sprinkling.

563. BITUMINOUS CONCRETE. In England a mixture of broken stone and tar, often called bituminous concrete, is sometimes used as a foundation. The only advantage claimed for it is that the pavement may be laid as soon as the foundation is completed and therefore it is more suitable for busy thoroughfares than hydraulic cement concrete. The bituminous concrete is sometimes laid as described in § 709, and sometimes by spreading and rolling the broken stone, and pouring tar * over the surface and then covering that with a thin layer of small stones and finally rolling. This foundation is more expensive and less reliable than hydraulic cement concrete.

Asphalt may be used instead of coal or gas tar, but it will not adhere to the stone unless both are at a higher temperature than that of the ordinary atmosphere. For a method of heating and mixing stone and asphalt, see § 600. On account of the expense asphaltic concrete is seldom used for a pavement foundation.

564. GRAVEL. Sandy gravel is sometimes used as a foundation for pavements—particularly brick and wood block. The proper thickness of the layer depends upon the nature of the soil and the thoroughness of the underdrainage; but it is usually 6 or 8 inches. It is customary to dump the gravel upon the subgrade directly from

* Often referred to in British engineering literature as a mixture of pitch, tar, and creosote oil; and often, but improperly, called asphalt or asphaltic cement.

wagons, and then to level off between the piles with shovels. By this process the bottom of the original piles is much more compact than the space between the piles; and rolling does not materially lessen the inequalities, since the roller, being usually a single cylinder of considerable length (§ 336), rides upon the top of the piles and does not compress the gravel between them. The result is that soon after the pavement is completed, the natural settlement of the gravel foundation causes the surface to be full of depressions.

The better and cheaper method is to level off the piles with a scraping road grader (§ 142), and then thoroughly harrow the gravel with a long-tooth harrow, after which the foundation should be rolled. For the best results, the gravel should be spread in layers not more than 2 or 3 inches thick. Brick pavements upon gravel foundation laid by this method have shown no depressions after many years, while those constructed with the utmost care by the preceding method with the same gravel on the same soil have been full of holes.

565. SAND. A stone-block and also a wood-block pavement is sometimes laid on a bed of sand. With stone blocks the sand is used more as a material in which to bed the blocks so as to make the upper surface of the pavement even, than as a foundation proper, the sand being simply a loose bed in which holes may be easily dug to receive the deeper blocks and from which material may be obtained to fill up under the shorter blocks.

566. PLANK. A wood-block pavement is sometimes laid on a course of plank upon a bed of sand or gravel. The gravel or sand should be laid substantially as described in § 564. The conditions that should be fulfilled by the plank will be considered in Chapter XIII—Wood-Block Pavements.

CHAPTER XIII.

ASPHALT PAVEMENTS.

ART. 1. THE ASPHALT.

568. NOMENCLATURE. Asphalt exists in various forms over widely distributed parts of the earth, and has been in somewhat common use for different purposes since the dawn of history; consequently the terms employed to designate it have been varied, and recently there has been no little confusion in the nomenclature, due in no small part to conflicting commercial interests. The following definitions are believed to be generally accepted, and are sufficiently exact for present purposes.

569. Bitumen. A natural hydro-carbon mixture of mineral occurrence, widely diffused in a variety of forms which grade by imperceptible degrees from a light gas to a solid, sometimes found in a pure state but usually intermixed with organic and inorganic matter. The bitumen series includes the following, in order of their density: natural gas, natural naptha, petroleum, maltha (at ordinary temperatures soft and sticky), asphalt (at ordinary temperatures stiff and non-sticky), glance pitch (dry and brittle).

570. Asphalt. A general name for the solid forms of natural mineral bitumen. Asphalt is distinguished from coal in being soluble in bisulphide of carbon and in benzole. Coal, peat, etc., are called pyro-bitumens because they yield an artificial bitumen by distillation. Asphalt is usually found associated with various mineral and organic substances. Asphalt is sometimes popularly called mineral pitch and mineral tar: and different varieties of asphalt are called grahamite, albertite, gilsonite, wurtzelite, uintatite, turrellite, etc.

The term asphalt is the English equivalent of asphaltum, the Latin form. Asphalt and bitumen are frequently used synony-

mously, but usually in paving literature bitumen is employed to designate the valuable hydro-carbon compounds in the native asphalt.*

571. *Crude Asphalt.* The native mixture of bitumen, sand, clay, water, organic matter, etc.

572. *Refined Asphalt.* The native mixture after it has been freed wholly or in part from water and organic and inorganic matter by being heated. Commercial refined asphalt contains considerable earthy matter; in fact commercial refining consists virtually in driving off the water and volatile oils, and incidentally in removing a little earthy matter.

573. *Rock Asphalt.* A limestone or sandstone naturally impregnated with asphalt. Rock asphalt is the principal form of asphalt used in Europe for paving purposes, and is usually there designated as asphalt. Some European commercial interests insist that only rock asphalt is entitled to be called asphalt.

574. *Asphaltic* or *Bituminous Limestone.* A limestone naturally impregnated with asphalt.

575. *Asphaltic* or *Bituminous Sandstone.* A sandstone naturally impregnated with asphalt.

576. *Compressed Asphalt.* In Europe, particularly in France, a rock-asphalt pavement is frequently referred to as being made of compressed asphalt, or, in French, asphalte comprimé.

577. *Asphalt Mastic.* A term frequently applied to refined asphalt, particularly to that obtained from bituminous rocks, and is usually in the form of cakes, which are melted and mixed with sand and used for making pavements and sidewalks, chiefly the latter (see § 919).

578. *Asphaltic Cement.* Refined asphalt which has been mixed with some solvent to increase its plasticity, adhesiveness, and tenacity.

579. *Asphalt Pavement.* A pavement composed of sand or pulverized stone held together by asphalt. In America an asphalt pavement is ordinarily understood to be a comparatively thin layer of sand held together by asphalt laid upon a bed of hydraulic

* For a scientific classification of hydro-carbons and allied substances and also for a classification of bituminous compounds which employs neither asphalt nor bitumen, see Annual Report U. S. Geological Survey, 1900–01, Part I, p. 220.

cement concrete; but in Europe the term asphalt pavement is understood to be a comparatively thick layer of asphaltic limestone or asphaltic sandstone, with or without a hydraulic concrete base.

580. *Asphaltic Concrete.* Broken stone bound together with asphaltic cement.

581. *Asphalte Comprimé.* The French equivalent of compressed asphalt—see § 576. This term is employed to indicate that the material is compressed in place, in contradistinction to being simply applied with a trowel.

582. *Asphalte Coulé.* The French equivalent of asphaltic mastic—see § 577. It is applied with a trowel without other compression.

583. GENERAL CHARACTERISTICS. As usually found asphalt is of a dark brown or glistening black color. It varies in hardness from a viscous liquid to about 3½ on the Dana scale. The streak is almost uniformly brown, sometimes brownish-black; and the fracture is dull and conchoidal. When rubbed or freshly broken, it emits a peculiar bituminous odor, which is not disagreeable although a little sour smelling. Before the blow-pipe, the solid varieties are quickly melted; and all are readily evaporated and burned, and leave as ash, the organic and inorganic impurities, which are usually found in it in smaller or larger quantities. Its specific gravity in the natural state varies from 0.96 to 1.68 according to its porosity and the amount and the character of the impurities present. It is insoluble in water, but is more or less soluble in carbon bisulphide, alcohol, turpentine, ether, naptha, and petroleum.

Coal-tar, or gas-tar, has an appearance somewhat like asphalt, and is sometimes used as a substitute for it or as an adulterant. Tar is not so valuable for paving purposes as asphalt, since it more easily loses its cementing qualities by vaporization and oxidation. The principal method of distinguishing asphalt and coal-tar, available to the layman, is the odor. The tar emits a sharp, acrid odor; while both the crude and the refined asphalt when cold give a weak clay-like odor, and must be rubbed to obtain the distinctive bituminous odor. If tar is mixed with asphalt, the presence of 25 per cent will be revealed by the odor. This is the proportion of tar in the vulcanite or coal-tar pavements laid in Washington from 1877 to 1887. When

being laid, tar gives off a bluish vapor, while asphalt emits a white vapor. Expert analysis is necessary to detect the presence of tar when mixed with asphalt in small quantities. The following method will certainly detect 5 to 7 per cent of tar. "Extract the bitumen with carbon disulphide, filter, evaporate to dryness, and heat the residue till it can be ground to a dry powder; 0.1 gram is treated with 5 c.c. of fuming sulphuric acid for 24 hours and is then mixed by continuous stirring with 10 c.c. of water. If coal-tar be present, the solution will be of a dark brown or blackish tint; if not, the solution will be of a light yellowish color."

584. Asphalt limestone varies in color from chocolate brown to black when freshly broken, the color being darker as the proportion of asphalt is greater. The percentage of asphalt permeating the limestone varies in different deposits and in different parts of the same mine, usually ranging from 1 to 20 per cent. The fracture of asphaltic limestone is irregular, and the grain is very fine. Under the microscope the smallest particle is coated with asphalt. If cut by a sharp blow of an axe, it appears grayish white along the cut, due to the forcing out of the asphalt and the leaving of the particles of limestone exposed. If a piece contains about 10 per cent of asphalt, it can be warmed and broken in the hands, and a piece heated over the fire falls apart; and if heated in a pan and held for an hour at a high temperature, the asphalt is driven off, and a gray, powdered limestone remains. If a sample contains more than about 4 per cent of asphalt, a bituminous odor is perceptible when the piece is freshly broken.

585. Asphaltic sandstone contains from 1 to 70 per cent of asphalt. The grain is sometimes dense and sometimes porous, sometimes very fine and sometimes coarse. Small particles of clay, little shells, and various other substances are often present. The color is almost invariably black. A piece heated upon a stove quickly falls in pieces if it contains more than 6 per cent of asphalt. Asphaltic sandstone often contains considerable quantities of maltha and petroleum which injure it for paving purposes.

586. Chemical Composition. Asphalt is not a mineral of definite chemical composition. Generally, it is a compound consisting of various hydro-carbons, which can be separated from each other only with great difficulty. Its chemical composition when

pure is: carbon, 80 to 88 per cent; oxygen, 0.5 to 10 per cent; hydrogen, 9 to 11 per cent; nitrogen, 0 to 1 per cent. Asphalt is often found mixed with other minerals, which may be called impurities, the most common of these being sulphur, which sometimes constitutes from 1 to 10 per cent of the whole. Varieties of asphalt from different localities seldom, if ever, agree with each other in chemical composition.

Asphalt may be separated, with more or less readiness, into several different substances which differ somewhat in chemical composition and widely in physical properties, the presence or absence of which has an important influence on the value of the asphalt for paving purposes. The principal of these substances are asphaltine, petroline, and retine. Under the head of asphaltine has been classed that part of the asphalt which is soluble in chloroform and bisulphide of carbon, and not in ether or naphtha; under the head of petroline has been classed that part which is soluble in ether and naphtha; and under retine has been classed that part which is soluble in alcohol. Asphaltine is hard and brittle, requires a high heat to melt it, or burns without becoming melted, and has very little, if any, of the adhesive qualities which make asphalt useful as a cement. Petroline is softer than asphaltine, becomes fluid at a lower temperature, has great adhesive or cementitious qualities, and is the valuable part of asphalt for most industrial work. Retine possesses the character of vegetable resin, and is not considered as adding anything to the value of asphalt for paving purposes.

It is very questionable, however, whether this division is well founded. Chemists differ widely as to the quantities of each of these so-called elements found in samples from the same locality, the results varying with the details of the methods of making the determinations, and with slight variations in the solvents employed.

Recently investigators are inclined to class all the components of asphalt under two heads only, the active and the inert. The active element is that part which is easily melted by heat, is readily soluble in ether or naphtha, and is highly adhesive and cementitious; while the inert material is the hard and brittle part which is not readily melted by heat, and which adds nothing to the cementitious properties of the asphalt. The ratio in which the active and the inert constituents are combined is the true index of the value of the

asphalt for use as a cement; but for other industrial purposes, such as insulating electric wires, etc., it has no practical value, for the active and the inert constituents appear to be equally good as non-conductors.

Asphalts from different sources should not be compared by their chemical analyses unless exactly the same methods and solvents have been used in each case. Further, it has been found that the chemical analysis of asphalt is not a reliable indication of its value as a cement, since asphalts having practically the same composition differ comparatively widely as to their physical properties.

587. PHYSICAL PROPERTIES. Crude and also refined asphalts from different localities differ widely in consistency, in susceptibility to changes of temperature and to changes by age, in stability at high temperatures, cohesiveness, adhesiveness, elasticity, etc. Not infrequently data are given to prove the alleged superiority of an asphalt in one or more of these particulars; but there is no recognized standard for testing the physical properties of asphalt, and the results of such tests are usually stated in terms so general as to be of no scientific value. For example, the viscosity at different temperatures is stated in such terms as "compressible," "easily bent," "malleable," "softens," "melts," "flows," etc. The results depend upon the details of the method of making the tests and upon the degree to which the asphalt has been refined; and as a rule such tests are useless except perhaps in comparing two asphalts tested at the same time under the same conditions.

Some natural asphalts are so hard and brittle that before being used for paving purposes they must be softened by adding some fluxing material or solvent, as a fluid bitumen or residuum of petroleum; and the physical properties of the mixture, called asphaltic cement, are usually examined very carefully to determine the probable quality of the resulting pavement, for which purpose standard tests have been devised. For the method of making such tests see § 610.

588. ORIGIN OF ASPHALT. Although it is generally conceded that asphalt is the oxidized residue of petroleum, and that petroleum is derived from vegetable or animal substances, there is a considerable difference of opinion as to its ultimate origin and as to the manner in which its production has gone forward. For a careful

consideration of the several theories, see the Origin and Accumulation of Petroleum and Natural Gas, by Prof. Edward Orton, in Vol. VI, Report of Geological Survey of Ohio, p. 60–100.

589. Location of Mines. Asphalt is found mixed with more or less earthy and vegetable matter, or impregnating limestone or sandstone. The localities where it is found are shown in Table 39. "One or more mines are worked in each of these countries, except, perhaps, Columbia, Indian Territory, Montana, New Mexico, Michigan, Washington, and Dalmatia." The principal sources of supply will be considered separately.

TABLE 39.

Location of Asphalt Deposits.*

Ref. No.	Mixed with Earthy Matter.	Impregnating Limestone.	Impregnating Sandstone.
1	Bagdad	Austria	California
2	California	California	Colorado
3	Colorado	Dalmatia	Cuba
4	Columbia	France	France
5	Indian Territory	Germany	Germany
6	Mexico	Hungary	Indian Territory
7	Montana	Indian Territory	Kentucky
8	Palestine	New Mexico	New Mexico
9	Peru	Michigan	Russia
10	Texas	Italy	Texas
11	Trinidad	Russia	Utah
12	Utah	Sicily	....
13	Venezuela	Spain	....
14	....	Switzerland	....
15	....	Texas	....
16	....	Utah	....
17	....	Washington	....

590. Trinidad Asphalt. The Island of Trinidad near the northeast coast of Venezuela, South America, supplied something like 90 per cent of all the asphalt used in the world from about 1875 to 1900. At present the Island of Trinidad is the main source of supply of the asphalt used in the United States.

The island contains about 1,750 square miles.† Near the south-

* Natural Asphaltum and its Compounds, by J. W. Howard. A pamphlet published by Rensselaer Society of Engineers, Troy, N. Y.. 1894.

† For an elaborate description of the island and of the asphaltic products, see the Report of the Inspector of Asphalt and Cements of Washington, D. C., for the year 1891-92, pages 464-98 of the Report of the Engineer Commissioner of the District of Columbia for 1891-92.

west corner is the so-called pitch-lake, which has an area of about 115 acres. The surface of the lake has an elevation of 138 feet above the sea-level, and the asphalt has a depth of 78 feet near the center. The surface of the lake has a slight fall from the center toward the sides, and a general inclination toward one side, and is covered with irregular flattened domes, separated by channels of flowing water a few feet wide and a few inches deep. There are several islands 50 to 60 feet in diameter scattered over the surface of the lake, which have sufficient depth of soil to support the growth of large trees. The surface of the asphalt is sufficiently hard that teams may be driven over it; but the whole mass is in constant motion around several vortices, as shown by trunks of trees which rise and after a time disappear again. Excavations made during the day close up during the night. At a place in the center, called the boiling spring, soft pitch wells up, but soon becomes hard. The appearance of boiling is due to the escape of large volumes of sulphuretted hydrogen.

The asphalt is excavated with picks and shovels, conveyed to the shore in carts, and lightered to vessels off-shore. On the voyage it becomes compacted into a solid mass and must be again broken up with picks. The crude asphalt is mixed with much earthy and a little vegetable matter and water and is dark brown, brittle, and as dense as dry peat.

The crude material is refined by placing it in kettles or open tanks and heating it for three or four days, during which time the water is evaporated, the vegetable matter rises to the surface and is skimmed off, and the earthy material settles to the bottom. Although this is called refining, it is really little more than a drying process, since but little mineral matter subsides, and only the water and the volatile oils are driven off. The mineral matter, if inert and insoluble in water, is not detrimental to an asphalt for paving purposes; but the non-bituminous organic matter and the soluble mineral matter are prejudicial. Great care is required in the refining process not to heat the asphalt to a point where chemical changes take place. The refined asphalt must be softened by the addition of some fluxing material before it is ready for use in the pavement —see § 604.

591. The above refers to asphalt obtained from the so-called

lake; but asphalt is also mined from the slopes between the lake and the sea. The former is called lake asphalt, and the latter land or overflow asphalt, or less frequently iron pitch. Both have the same origin, the land asphalt simply being asphalt from the lake which has overflowed the surrounding land. The land asphalt, having been exposed to the elements for a longer time than the lake asphalt, and having lost part of its volatile oils and having been partially oxidized, is less plastic than that from the lake. For a number of years there was a sharp commercial controversy as to the alleged superiority of the lake asphalt; but at present the controversy has practically subsided. The composition of neither is uniform, and therefore the above difference is not of much importance, particularly as only about 10 or 12 per cent of the asphalt mixture in the pavement is asphalt. The average composition of the three grades is shown in Table 40.

TABLE 40.

COMPOSITION OF TRINIDAD ASPHALT.*

Ref. No.	Components.	Lake.		Land.
		Soft.	Hard.	
	CRUDE MATERIAL:			
1	Bitumen soluble in carbon bisulphide	34.50%	38.14%	37.76%
2	Earthy matter	25.05%	26.38%	27.57%
3	Vegetable matter	6.35%	7.63%	8.05%
4	Water	34.10%	27.85%	26.62%
	Total	100.00%	100.00%	100.00%
	REFINED MATERIAL:			
5	Bitumen soluble in carbon bisulphide	52.36%	52.87%	51.58%
6	Earthy matter	38.00%	36.56%	37.74%
7	Vegetable matter	9.64%	10.57%	10.68%
	Total	100.00%	100.00%	100.00%

*Compiled from Report of Engineer Commissioner of District of Columbia for 1891-92, pages 476-77.

592. Bermudez Asphalt. This is the name given to the asphalt obtained from a lake or deposit situated in the state of Bermudez, Venezuela. This deposit is said to have an area of over 1,000 acres.

It is situated about 60 miles from the coast, up the San Juan river, and about 51 miles distant from it. A narrow-gage steam railroad connects the deposit with the shipping point, so that vessels drawing 18 feet of water can be loaded directly from the cars.

The crude asphalt is of the same variety as the Trinidad, namely, bitumen mixed with sand, clay, and vegetable matter. The average composition of the crude material is about as follows:

Bitumen soluble in carbon bisulphide	93.54	per cent
Earthy matter	2.16	" "
Vegetable matter	1.15	" "
Water	3.15	" "
Total	100.00	" "

The refining process is similar to that described for Trinidad asphalt (§ 590); but it is much more rapid, owing to the smaller amount of water and mineral matter present. In manufacturing asphaltic cement, the Bermudez asphalt requires much less of the fluxing agent than does the Trinidad on account of the large amount of oil contained in the former.

593. California Asphalt. The aborigines of California used asphalt for making their canoes water-tight and for cementing their utensils and weapons; and the Spanish Mission fathers who first civilized the country used it for making floors, walks, reservoirs, and water conduits. The Mexicans who settled the country after the establishment of the missions also found many uses for the asphalt, and there are still to be seen numerous examples of their cisterns, pavements, walks, etc., in a good state of preservation. These uses were entirely local; and no steps were taken to extend the applications of asphalt until in 1884 some bituminous sandstone was shipped from Santa Cruz. In recent years the asphalt industry of the state has reached a considerable development; and at present California is the principal producer of asphalt in the United States. Probably this state not only has larger quantities of asphalt than any other equal area in the world, but has a greater variety of forms —solid and liquid asphalt, and asphaltic limestones and sandstones, —and in more localities.

Maltha ("fluid bitumen or liquid asphalt") is found in small quantities in a number of places in the state, but the deposit of most

commercial value is situated in Santa Barbara county, about 13 miles east of the city of Santa Barbara, on the shore of the Pacific Ocean. The deposit consists of a large body of bituminous sand covering an area of about 75 acres to a depth of 25 feet. The maltha is supposed to be supplied from a stratum of bituminous shale upon which the sand rests. The sand is covered with from 6 to 8 feet of surface loam which is washed off into the sea by a 12-inch stream of water under pressure supplied by steam pumps. A thin layer of clay resting directly upon the sand is next removed with spades. The sand is then loaded into cars with hot spades, and is drawn by a cable up an inclined way to the refinery, where it is dumped into a mixer consisting of a steam-jacketed cylinder in which revolving arms break up the lumps. The material then falls into vats of boiling water, the maltha floats, and the sand, sinking to the bottom, is carried away by mechanical means. The maltha flows from the surface of the water through a spout to a tank whence it is pumped into a storage tank at a higher elevation. From there it runs into refining kettles, where it is subjected for twenty-four hours to a heat which beginning at 100° F. is gradually raised to 240° F. This process removes all aqueous vapors and volatile oils, and then the material is ready for use. The refined product contains an average of 98.26 per cent of pure bitumen, and 1.74 per cent of mineral matter. This mine is the most extensive producer of natural fluid bitumen, or "liquid asphalt," in the world. This liquid is much used for fluxing the harder asphalts.

The most extensive deposit of solid asphalt in California is at La Patera, Santa Barbara county, 12 miles west of Santa Barbara immediately on the sea-shore. There are facilities for both rail and water transportation. The deposit covers an area of several hundred acres, and the material is mined much as coal is. The supply, as in the case of the maltha, comes up from below, slowly but continuously. It is not soft, but is friable, and breaks readily under the pick. The sand is pulverized and conveyed to a large vat where the asphalt is dissolved out by gasoline. The gasoline overflows from the tank and runs down a pipe-line over a rough and sandy country 27 miles to the sea-shore, where it is distilled off and pumped back to the mine. The asphalt is put up in barrels for shipment. The average composition of the asphalt is as follows:

Bitumen soluble in bisulphide	59.15 per cent.
Earthy material	39.75 " "
Vegetable matter	1.10 " "
Total	100.00 " "

Asphaltic limestone and sandstone are found at a number of places in California, in all degrees of richness and consistency. The principal deposits are at Santa Cruz, in Santa Cruz county, at San Luis Obispo, in the county of the same name, and at Kings City, in Monterey county. The asphalt is extracted from the stone by heating the mass in a tank and drawing off the liquid asphalt, which is shipped to various parts of this country to be used for paving purposes.

The base of the California petroleums is asphaltic, as distinguished from the paraffin base of the eastern oils, and the process of refining petroleum leaves the asphalt or maltha as a residue, and at several places asphalt is produced from the crude petroleum.

594. Other American Asphalts. Asphalt is found in quantities of considerable commercial importance in Utah, Colorado, Indian Territory, Texas, and Kentucky. For a detailed account of the geological occurrence of asphalt in these states, see an article by George H. Eldridge on Asphalt and Bituminous Rock Deposits in the United States, in Annual Report of U. S. Geological Survey for 1900–01, pages 219–464.

595. European Asphalts. Asphalts from which pavements are made are found in Val de Travers, Canton of Neuchatel, Switzerland; Seyssel, Department of Ain, France; Vorwohle and Limmer, Germany; and Ragusa, Sicily. The first two are the most important sources of supply. Although widely distributed, these asphalts are practically of the same nature, as shown by Table 41, page 397, and occur in strata varying in thickness from 6 to 23 feet. The rock is quarried, and then the blocks are crushed to the size of an egg by rollers provided with teeth and revolving at different speeds. These pieces are next reduced to a powder in a Carré disintegrator, and the powder is sifted to uniform fineness. It is then ready for use in making pavements. Large quantities of Trinidad asphalt (§ 590) are shipped to Europe and added to native asphaltic limestones deficient in asphalt. On the other hand, asphalt is extracted from European asphalt rocks and shipped, usually in the form of

cakes weighing 50 to 60 pounds, to this country to be used in making artificial paving compounds.

TABLE 41.

CHEMICAL COMPOSITION OF EUROPEAN ASPHALTIC LIMESTONES.

Ref. No.	Components.	Val de Travers.*	Seyssel.*	Limmer.	Vorwohle.†	Sicilian.†
1	Bitumen soluble in carbon bisulphide......	10.10	8.00	14.30	5.37	8.85
2	Carbonate of lime.....	87.95	89.55	67.00	90.80	87.50
3	Volatile at 100° C.....	0.50	1.90	1.18	0.34	0.80
4	Miscellaneous.........	1.45	0.55	17.52	3.49	2.85
	Total............	100.00	100.00	100.00	100.00	100.00

* Analysis by Laboratoire de l'École des Ponts et Chaussées.
† Analysis of Sicilian Paving Co., New York City.

ART. 2. SHEET ASPHALT PAVEMENTS.

596. A sheet or monolithic asphalt pavement consists primarily of (1) a wearing coat 1½ to 2 inches thick composed of asphaltic paving cement mixed with sand; (2) a binder course composed of broken stone and asphalt cement; and (3) a foundation of hydraulic cement concrete or an old pavement of cobble stones, granite blocks, bricks, or the like. In this country when the term asphalt pavement is used the above form is usually intended. The term sheet or monolithic pavement is not distinctive, since rock asphalt also is laid as a continuous sheet; but no confusion is likely to result, since in this country the term sheet is commonly used to distinguish the monolithic form from the asphalt block pavement, and since in Europe only one form of asphalt pavement is used, monolithic natural rock. In contra-distinction to a pavement made of natural asphaltic limestone or sandstone, the above pavement could with some propriety be called an artificial asphalt pavement, or the wearing coat could with still more propriety be called an artificial asphaltic paving compound; but the distinction is not important since the sheet asphalt pavement is laid almost exclusively in this country and the rock asphalt almost exclusively in Europe.

597. HISTORICAL. The first artificial sheet asphalt pavement in this country was laid in Newark, N. J., in front of the city hall in

1870. In 1873 a small piece was laid on Fifth Avenue, New York City, opposite the Worth Monument. A few other experimental sections were laid; but the first test on a large scale was in 1876 on Pennsylvania Avenue in Washington, D. C. Preceding 1882, outside of Washington, D. C., there were not more than half a dozen streets in this country paved with any form of asphalt; but since that date, asphalt pavements have increased rapidly, and now hundreds of miles of it are in use on the streets of American cities. The following statistics show the rapid growth of this industry: In this country in 1880 there were 300,000 square yards of sheet asphalt pavements; in 1885, 1,800,000; in 1890, 8,100,000; in 1895, 21,500,000; in 1900, 38,000,000.* In Europe in 1900 there were only about 3,000,000 square yards of asphalt pavements of all kinds.

598. The Foundation. Since the sheet-asphalt wearing surface has no power in itself to act as a bridge, it is essential that it be placed upon a firm unyielding foundation; and consequently it is nearly always placed upon a bed of hydraulic cement concrete, prepared as described in Art. 2. Chapter IX, page 367. For heavy city traffic, the concrete is usually six inches thick; and for light traffic, it is sometimes only 4 inches thick. The proper thickness will depend upon the weight of the traffic, the strength of the concrete, and the bearing power of the soil.

Occasionally the asphalt is laid upon a bituminous-cement concrete (§563). The chief advantage claimed for the bituminous concrete is that the asphalt wearing-surface adheres more firmly to it than to the hydraulic concrete, and thus prevents weather cracks (§ 654) and waves (§ 655). An additional advantage of bituminous over hydraulic concrete is that less time is required for the former to set. On the other hand, the bituminous concrete is weaker and less reliable, and usually is more expensive. Further, in repairing the wearing surface, it is difficult to separate the top coat from the bituminous base so as to secure a uniform smooth surface. Bituminous concrete never was so common as hydraulic-cement concrete for a foundation, and has now practically been abandoned.

It is necessary that the concrete be thoroughly dry before the

* P. W. Henry, Vice-President and General Manager of Barber Asphalt Paving Co., in *Engineering News*, Vol. 45, p. 183.

asphalt mixture is laid upon it, as the generation of steam caused by placing the hot material upon a damp foundation will produce blistering and possibly disintegration of the wearing coat. This is a matter that needs close attention in laying an asphalt pavement. To dry the foundation after a rain or during damp weather, fine hot sand is sometimes spread over the concrete and then swept off; but this method is expensive and not very effective, and besides there is liability that enough sand will be left upon the foundation to interfere with the adhesion of the asphalt.

599. Often an old pavement of broken stone, cobble stones, granite blocks, or brick is used for a foundation for an asphalt pavement. All of these give fairly good results, but it is important that the surface of each shall be perfectly clean and dry when the asphalt wearing coat is laid.

600. BINDER COURSE. This is a layer about 1½ inches thick of broken stone cemented together with asphaltic paving cement (§ 603), and rolled in place while hot. The purpose of this course is to bind the wearing coat and the foundation or base together, and to prevent the wearing coat from lifting from the foundation or from being pushed along in a wave.

The broken stone is screened to pass a 1-inch or a 1¼-inch mesh, and after being heated not more than 5 or 10 per cent should pass a No. 10 screen. An excess of fine stone is undesirable, since more asphalt is required to coat it, and also since the coarser stone gives a rougher upper surface and therefore affords a better anchorage for the top course of the pavement.

The apparatus for heating the stone consists of a revolving steel cylinder about 30 inches in diameter and 12 to 14 feet long, set at a slight inclination. On the interior are deflectors to distribute the stone in its course through the drum. The cylinder is heated by means of either wood or fuel-oil, preferably the latter, as it can be more closely regulated. The broken stone to be heated is carried by an endless chain and bucket elevator to a hopper just above the cylinder in which it is to be heated, from which it is fed into the heating cylinder. The temperature of the stone as delivered from the heater is controlled, not only by the fire, but by the rate at which it is fed into the heating drum. The stone should leave the heating drum at a temperature of about 300° F.

The hot stone is fed into a mixer which consists of an inclined steel cylinder 2½ to 3 feet in diameter and 10 to 14 feet long. On the axle of this cylinder are blades which push the material through the drum and also aid in mixing the stone and the asphaltic cement. When the mixing is well regulated, the hot stone is fed into the upper end of the mixer, the asphaltic cement at a temperature of 300° to 325° F. is poured over the stone in proper proportions from a dripping tank, and the binder drops continuously out of the lower end of the mixer into a cart. Considerable skill is required in regulating the temperature of both the stone and the cement, and in adding the proper amount of the latter.

The asphaltic cement is the same as that used for the wearing coat (see § 603), except that it is mixed much softer. The asphalt for the wearing coat is usually mixed to a consistency represented by a penetration of 70° to 90° with the Dow needle (§ 613), while the cement for the binder course has a penetration of only 45° to 55°. This cement is added to the hot stone in the proportion of 6 to 7 pints of cement to 1 cubic foot of stone; or in other words, the binder is mixed so as to contain about 5 per cent of bitumen soluble in carbon dioxide. Each fragment of stone should be thoroughly coated with cement, but there should be no excess. If too much cement is used, it either drains off on its way to the street, or is drawn by capillary attraction into the wearing coat and causes it to disintegrate (§ 642). If too little cement is used, the fragments of the stone will not adhere firmly together and the whole course is liable to break up under the roller. The surface of the coated stone should be bright and glossy, and should not appear dull and dead, a condition which is due either to an overheating of the stone or to a lack of cement.

While hot, the mixture is hauled to the street, distributed uniformly over the foundation, and rolled until it is cold, the foundation having previously been made clean and dry. After being compacted, the binder course should have a thickness of about 1½ inches, and should firmly adhere to the foundation.

601. The above method of making the binder course is the one employed at Washington, D. C., but sometimes a practice somewhat different prevails. The stone is made very fine, one quarter to one half of an inch in greatest dimension, and the cement is made of

the same penetration as that in use in the wearing surface. The finer stone requires more asphalt to coat it, but the resulting concrete is stronger, and is less likely to pull to pieces in hauling the wearing coat to place; but with the finer stone the upper surface is smoother, and therefore offers less resistance to the pushing of the top coat into waves. On the whole the finer stone and the softer cement are preferable, since the binder then is more elastic and less liable to damage in hauling the wearing coat over it.

Formerly coal tar was used as the cement in the binder course, but it has nearly been abandoned, owing (1) to its variability and (2) to the fact that it must be used at a lower temperature (about 220° instead of 300° to 325°), and consequently chills more easily, (3) to the fact that it is a weak cement, and therefore is more liable to damage in placing the top course, and (4) because it sometimes contains an oil which being absorbed by the wearing coat causes the asphalt to disintegrate.

602. CUSHION COAT. The binder course is occasionally entirely omitted owing to the expense necessary for maintaining separate appliances for mixing the stone and the asphalt of the binder course. In this case, a thin course of material of the same composition as the wearing coat (§ 625), except that it contains a little more cement, is laid instead of the binder course, and is called a cushion coat. The cushion coat is usually from ½ to 1 inch thick, and being richer in cement adheres more firmly to the foundation than would the top coat.

603. ASPHALTIC CEMENT. The cementitious element of the wearing coat consists of commercially refined asphalt mixed with a softening or fluxing agent. The asphalt has already been discussed (see Art. 1).

604. Softening Agent. Many of the asphalts are so hard and brittle that before being used for paving purposes, it is necessary to soften them by the admixture of oil or liquid bitumen. The selection of the proper fluxing agent for the harder asphalts is a very important matter. For example, refined Trinidad asphalt, which consists of 52 to 56 per cent pure bitumen, is usually mixed with about 18 pounds of fluxing material (petroleum residuum) per hundred pounds of asphalt; and hence the bitumen added in the fluxing material is equal to about one third of that originally in the

asphalt, or the bitumen added in the softening agent is equal to about one fourth of that in the finished pavement.

There is a considerable difference of opinion as to the value of different fluxing agents, and the selection of a proper flux involves several unsettled chemical problems.

The properties required of an asphaltic flux are: 1. It should contain a material volatile under 300° F., as otherwise the volatile matter will be given off while the paving cement is being heated preparatory to its being mixed with the sand of the wearing coat, and consequently the asphalt will lose its cementing power. 2. The flux should be as fluid as possible in order that the greatest softening effect may be produced by the least quantity, as ordinarily the fluxing agent is comparatively expensive. 3. The softening agent should be chemically stable and not lose its fluidity by molecular change. 4. The fluxing agent should dissolve the asphalt and not simply form a mechanical mixture with it. The asphalt consists of asphaltine and petroline (§ 586), the former being entirely devoid of cementing power and the latter highly cementitious; and therefore the fluxing agent should dissolve the asphaltine.

There are two general classes of asphaltic flux in common use: (1) petroleum residuums or artificial bituminous fluxes, and (2) malthas or natural bituminous fluxes. The first is composed of liquid paraffins, and the second of fluid natural bitumens of the same nature as asphalt. There are two forms of each in more or less general use. There are therefore four fluxing agents; viz.: (1) residuum from the paraffin petroleums of Pennsylvania; (2) a specially prepared paraffin,—petroleum residuum known as Pittsburg flux; (3) residuum from the asphaltic petroleums of California; and (4) maltha. Until recent years the first was the only fluxing material in use, but at present all four are in more or less common use.

605. *Paraffin-Petroleum Residuum.* "The best [paraffin] petroleum residuum is a heavy thick oil at 70° F., which begins to solidify at 58° F., and becomes solid at 48° F., the solidification being due to a crystallization of a portion of its constituents. At a temperature of 90° F. it becomes very limpid. It is very non-adhesive in character; and, when in a solid condition from cold or other causes, it is very waxy in consistency and entirely lacking in cementing properties. It gradually loses its fluidity with age, ap-

parently by the separation from the residuum of a light brown amorphous solid." * Whether or not petroleum residuum completely dissolves the bitumen of asphalt has been an open question for several years, but some recent experiments † seem to show that it does not. "Judging from the physical properties of this residuum and its chemical relations to asphalt bitumen, it is not a desirable flux." ‡

"The best petroleum residuums comply with the following tests: 1. The specific gravity ranges between 20° and 23° Baumé. 2. The flash point (as taken in a New York Board of Health oil tester) is between 300° and 425° F. 3. On keeping the residuum at a temperature of 400° F. for thirty hours, it must lose between 2 and 6 per cent of oil. The residue in the retort should be fluid at 75° F., and on cooling should not show a coarse crystallization. The quantity of residuum necessary to soften [Trinidad] asphalt into a cement containing bitumen whose penetration is 80° (District of Columbia standard), should not be over 33 per cent of the total quantity of bitumen in the asphalt. 4. The residuum must show only the slightest signs of having been 'cracked' [i. e., that the hydro-carbon compounds have been broken up into new components in the course of manufacture]. An oil that has been 'cracked' on being examined through the microscope reveals numerous black particles floating in it. The particles are insoluble in petroleum naphtha. but are soluble in carbon bisulphide, and resemble asphaltine."

606. *Pittsburg Flux.* This is made by heating paraffin-petroleum residuum with sulphur, which favorably changes the paraffin, and has been used to a limited extent.

607. *Asphalt-Petroleum Residuum.* California petroleum, in asphalt paving literature often called asphalt oil. is an excellent solvent of asphalt, and in recent years has been much used as a fluxing material.

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* A. W. Dow, Inspector of Asphalts, Washington, D. C., in Report of the Operations of the Engineering Department of the District of Columbia for the year ending June 30, 1898, p. 124.

† *Ibid.*, p. 126.

‡ *Ibid.*, 1897, p. 172.

608. *Maltha.* This is a liquid bitumen which is often, but somewhat improperly, called liquid asphalt. In several respects it resembles asphalt-petroleum residuum; but in other particulars it is quite different. It is unsuitable for use as a fluxing agent for asphalt, since a considerable part of it, by some authorities * estimated at as high as 20 to 25 per cent, is itself asphalt and has no fluxing effect upon the asphalt to which it is added.

609. Mixing the Asphalt and the Flux. The refined asphalt is brought to a temperature of about 300° F., and, to produce rapidly a uniform mixture, the flux also is heated to about the same temperature. The proper amount of the residuum to secure an asphaltic cement of the desired consistency (§ 613) is then added to the asphalt, the exact amount depending upon the consistency of the asphalt and the character and the fluidity of the flux. Trinidad asphalt, for example, requires about 17 or 18 per cent of paraffin-petroleum residuum. After adding the flux, the mixture is agitated for several hours with a current of air until it is quite homogeneous This agitation must be done with great thoroughness to insure a uniform cement, and must be continued whenever the material is in a melted condition, as a certain amount of separation takes place when the melted cement stands at rest. The resulting mixture is known as asphaltic cement; and if the mixing has been well done and the proper amount of suitable flux has been used, the cement is ready for use in the pavement.

610. Testing the Asphaltic Cement. To determine the suitability of the asphaltic cement for use in a pavement, it is necessary to test its chemical and physical properties. The chemical test consists in the determination of the per cent (1) of bitumen, (2) of foreign or non-bituminous organic matter, and (3) of inorganic matter; and the physical tests consist in determining (1) the consistency or the softness of the cement and its susceptibility to changes of temperature and to changes with age, (2) the stability of the cement at high temperatures, (3) the effect of water and of dilute ammonia upon the cement, (4) its adhesiveness, and (5) its cohesiveness.

611. *Chemical Composition.* The per cent of bitumen may be

* S. F. Peckham in Paving and Municipal Engineering, Vol. 7, p. 171.

determined in various ways, but is most easily done as follows:* "The asphalt is spread in a thin layer in a suitable dish (a nickel or an iron one will do), and kept at a temperature of 225° F. until it practically stops losing weight. The greater part, and in some cases all, of the water and some light oils are expelled in this way. From 2 to 10 grams (depending upon its richness in bitumen) of this substance is weighed in a large test tube (8 inches long by 1 inch diameter), the tare of which has been previously ascertained. The tube containing the substance is then filled to within 1½ inches of the top with carbon bisulphide and allowed to stand for a few minutes. Then the tube is tightly corked with a good sound cork, and is shaken vigorously until no asphalt can be seen adhering to the bottom. Care should be taken while shaking to keep one finger on the cork to prevent its being blown out. The tube should then be put away in an upright position and not be disturbed in the slightest way for two days, after which the carbon bisulphide is decanted off into a small bottle. As much of the solvent should be poured off as is possible before losing any of the residue. The tube is again filled and shaken as before, and put away for two more days. After the liquid has been carefully decanted the second time, the tube with the residue is dried first at a low temperature and then at 225° F. After cooling the tube is weighed. As there is always a small portion of the residue poured off in the solution with the bitumen, this solution must be evaporated and the bitumen burned off in a platinum dish, and the weight of the residue added to that in the tube."

During the year ending June 30, 1897, the per cent of bitumen in the asphaltic cement used in Washington, D. C., by the two paving companies doing work there was as follows, respectively: average 10.6 and 10.5, maximum 12.6 and 12.7, and minimum 9.2 and 9.0.

612. "The determination of the organic matter not bitumen, or, as it is often called, the foreign organic matter, is made by burning, in a tared platinum crucible, the residue left in the tube after extracting the bitumen." †

* A. W. Dow, Inspector of Asphalts, Washington, D. C., in Report of the Operations of the Engineering Department of the District of Columbia for the year ending June 30, 1897, p. 170.

† *Ibid.*, p. 170.

613. *Standard Consistency.* The softness or the consistency of an asphaltic cement is determined by measuring the distance a standard needle will penetrate the mass in a specified time. There are two forms of apparatus in use for this purpose, Bowen's and Dow's.

1. Bowen's Penetration Apparatus. This apparatus consists of a needle of standard weight and size, whose vertical motion is registered by an index moving over a graduated disk. This is accomplished by inserting a large sewing needle in the free end of a lever arm which is supported by a thread wound around a spindle. The spindle carries an index which moves over a graduated disk. On the spindle is a drum round which winds a thread supporting a weight which acts as a counterbalance to the weight of the lever arm. This counter-weight keeps the thread taut; and when the lever arm is raised, it turns the pointer on the dial. The penetration of a sample is taken by lowering the needle until it is just in contact with the surface, and then releasing a clamp which allows the needle to penetrate into the sample for a specified time—usually 1 second. At the end of the time the clamp is closed, and the degree of penetration is noted from the dial.

The sample must be kept at a standard temperature, usually 77° F. (25° C.) for at least half an hour before making the test. This is most accurately done by keeping the machine and samples in a small room maintained at the standard temperature; but is usually done, particularly at the mixing plant, by immersing the samples in a tank of water.

Preceding 1899, this apparatus was the standard in Washington, D. C., and the penetration of the Trinidad asphaltic cement used during the year ending June 30, 1897, by the two paving companies doing work there was respectively: average 77 and 85, maximum 83 and 100, minimum 74 and 76.

2. Dow's Penetration Apparatus. This consists of an ordinary No. 2 sewing needle fastened into the end of a small brass rod which in turn is fastened into the end of a metal tube about 4 centimeters (1.6 inches) long and 1 centimeter (0.4) inch in diameter. Mercury is poured into the tube to give it any desired weight from 30 to 300 grams. The brass rod and the tube with needle end down, slides freely up or down through a frame, and can be held in any position

by a clamp. The motion of the sliding part is communicated by a thread to an index arm moving over a graduated disk. The test samples are kept in a water-jacketed copper box, which rests in a tank supplied with inlet and outlet pipes whereby a constant temperature may be maintained. The apparatus has several minor devices to facilitate its use and to insure accuracy.*

The unit is the distance in hundredths of a centimeter that a No. 2 needle will sink into an asphalt paving cement in five seconds when weighted with 100 grams, the cement and the apparatus being at a temperature of 77° F. (25° C.). The penetration can be measured with accuracy to one fiftieth of a millimeter (0.000,8 inch). This instrument is a later invention and is claimed to be more accurate than the Bowen apparatus. Since Jan. 1, 1899, this instrument has been the standard in Washington, D. C., and the average penetration of the Trinidad asphalt cement used by the two companies doing the work in that city during the year ending June 30, 1899, was 36 and 45. In a rough way the unit of this apparatus is about twice that of the Bowen machine.

614. The proper softness or viscosity of the asphaltic cement depends upon the kind and the amount of the traffic, the range of atmospheric temperature, the character of the sand used (§ 621), and the susceptibility of the bitumen to changes of temperature (§ 615) and to changes with age (§ 616). No general standards have been established, and but little accurate information is known to the public concerning the experience in any city except Washington, D. C. The degree of penetration employed in that city with both the Bowen and the Dow apparatus is stated in the preceding section.

615. *Variation of Consistency with Change of Temperature.* The susceptibility of the paving cement to changes in temperature is determined by taking the penetration of the substance at several different temperatures and noting the variation caused by the rise or fall. The chief cause of the susceptibility to changes in temperature is the presence of the paraffin added in the fluxing agent. Paraffin at ordinary temperatures is an inert solid; but as soon as heated to the melting point it quickly liquefies, and then acts as so

* Report of Operations of Engineering Department of District of Columbia for the year ending 1898, p. 128–29.

much additional flux, thus suddenly changing the consistency of the asphaltic cement.

616. *Variation of Consistency with Age.* "All bitumens undergo a more or less rapid change with aging, a fact which appears to be due to two or possibly more causes. Two distinct changes manifest themselves. 1. A surface hardening takes place, probably due to indirect oxidation, and possibly to the volatilization of the light oils. It begins at the surface and gradually extends into the mass. 2. A hardening of the entire mass takes place, evidently due to polymerization, i. e., to new atomic arrangement. Both of these changes take place in all bitumens, but one or the other may predominate.

"The test is made as follows: The penetration of the sample is determined, after which it is put away for a week, when the penetration is again ascertained. If the sample is found to have appreciably hardened, a slanting cut is made into it with a keen, sharp knife, thus exposing a gradual descent from the surface into the interior of the cement. Penetrations are now taken down the side of this cut, beginning at the surface. In this way the increase in hardness of the surface, and also of the interior, over the original consistency is determined. It is well to continue this test for as long a period as possible, making examinations at intervals of every few weeks." *

617. *Stability at High Temperature.* The asphalt must remain at a high temperature for a considerable time in mixing it with the softening agent as well as in mixing the cement and the sand; and it is important that the asphalt mixture shall in this process lose none of its valuable properties. Owing to the great area exposed to evaporation the effect of high temperature is especially severe after the cement has been mixed with the sand. The lack of stability resulting from the loss of the light oils is manifested in different ways in different bitumens. Although generally true, it does not of necessity follow that the bitumen losing the most oil undergoes the greatest change in consistency. There are two methods of making this test, both of which should be used:

1. "The asphalt cement is mixed with standard sand in such proportions that the mixture will contain 10 per cent of bitumen.

* A. W. Dow, Inspector of Asphalts, Washington, D. C., Annual Report, 1897, p. 171.

This is done by keeping the ingredients in an oven for 15 minutes at 300° F., and then incorporating them by stirring. One portion of this mixture is then put aside to cool, while the other is kept at the temperature of 300° F. for a half hour longer. The bitumen is then extracted from both; and after having arrived at the same temperature, their penetrations are compared.

2. "The second method consists in keeping a quantity of the substance, equivalent to 20 grams of bitumen, at the temperature of 400° F. for thirty hours. The method of procedure is as follows: The substance is weighed in a short-necked, tubulated, 2-ounce retort, the tare of which has been previously taken. The retort is then hung in a copper cylinder so that the neck just protrudes. The copper cylinder is then jacketed with asbestos and provided with a thermometer. After being heated up to 400° F. for thirty hours, the retort is allowed to cool, and is then weighed. The per cent of loss should not be more than 8 per cent. The retort is then broken open and the character of its contents compared with that of the original substance." *

618. *Effect of Water and Ammonia.* "The action of water and dilute ammonia on an asphalt mixture is determined by molding an inch cube of the mixture under a pressure of 1,000 pounds. The cube is broken in two, one portion being placed in water or dilute ammonia, while the other portion is kept in the air. The two pieces are compared from time to time. If the piece has been acted upon by the liquid, the corners will be found to give away readily with a slight pressure of the finger. After soaking some time, it is well to evaporate the liquid to dryness and to note if any bituminous residue remains." *

619. *Adhesiveness.* Formerly the adhesiveness of asphaltic cement was supposed to be measured by the proportion of petroline (bitumen soluble in ether or naphtha) it contained; but the results differ so widely with different asphalts, with variations in the details of making the experiments, and with the purity of the solvents, that the test has been practically abandoned.

The adhesiveness has been tested in a few cases by cementing together with asphalt the ends of hydraulic cement briquettes and

* A. W. Dow, Operations Engineering Department of District of Columbia for 1897, p. 171.

then pulling them apart with a cement-testing machine. Brass briquettes have been used instead of the cement ones, the surface to which the asphalt is applied being left rough. When using these briquettes, they are heated in water to about 140° F., taken out and dried, and the separate ends dipped into the molten asphalt. The two ends of the briquette are then pressed together and allowed to cool, after which they are tested in the same manner as are hydraulic cement briquettes.

At present the only test in general use is to compare different asphalts for adhesiveness by the sense of touch.

620. *Cohesion.* Attempts have been made to determine the tensile and the compressive strength of asphaltic cement, by much the same methods as those employed in testing hydraulic cement, but owing to difficulties in making the tests the practice has not been generally adopted. The strength of asphaltic cement varies materially with the temperature, and flows perceptibly at ordinary atmospheric temperatures; and therefore the details of the experiments materially affect the results.*

621. THE SAND. The asphaltic cement is mixed with inert mineral matter, mainly sand, to form the wearing coat. The mineral matter constitutes about 90 per cent of the wearing coat, and its character and composition has an important effect upon the quantity and durability of the pavement.

The sand should be (1) clean and (2) sharp, and (3) be composed of grains not easily crushed, and (4) have as small a proportion of voids as possible. 1. It should be free from clay, loam or vegetable matter, because these substances are devoid of cementing power, are easily reduced to powder, and will prevent the cement from adhering to the sand grains. 2. The sand should have sharp angular grains rather than smooth round ones, since the former afford a better surface for the adhesion of the asphaltic cement, and since sand with angular grains is much less mobile and hence is more easily cemented into a solid mass which will not flow under traffic. 3. The sand grains should not be easily crushed by the

* For numerical results of the tensile and compressive strength of three asphalts, see Jour. Assoc. Eng'g Societies, Vol. 13, p. 492. For comparative results of the ductility of seven asphaltic cements, see Proc. Amer. Soc. of Municipal Improvements, Vol. 6, p. 150–51.

traffic, for, if they are broken after the pavement is laid, numerous surfaces will be produced which are not coated with cement, and to that extent the pavement will be weakened. 4. The sand should contain as small proportion of voids as possible, since less asphaltic cement will then be required.

622. The ideal condition is that each grain shall be coated and all interstices between the grains be filled with asphaltic cement, and hence the smaller the proportion of voids the less the cement required. Again, the asphaltic cement is more or less of a liquid having capillary action between the sand grains, and therefore the smaller the interstices between the grains the greater the force of attraction between the liquid cement and the sand. An example of the adhesive force of a limpid liquid is seen in a sand beach when the tide has just left it. The water holds the sand grains so firmly that a wagon can be driven over the sand without leaving a mark; but when the sand dries out, it becomes loose and mobile. This seems to indicate that the finer the sand the better; but fine sand is usually less sharp than coarse, and the finer the sand the greater the surface to be coated, and hence the greater the amount of asphalt required. The asphalt is not only more expensive than the sand, but it is less able to resist displacement by pressure; and consequently the greater the amount of asphalt present the more expensive the pavement, and the more liable it is to flow under traffic. On the other hand, the smaller the voids, the greater the binding action of the cement; and also the finer the sand the smaller the voids, although the per cent of voids may be greater than with sand having grains of graded sizes.

As far as is known, no experiments have been made to determine the relative value of different sands for asphalt pavements; but apparently the best sand is that in which the coarse and fine grains are so adjusted that the finer grains fill the voids between the coarser ones. To secure this condition, it has been the custom to mix a certain amount of pulverized limestone with the sand. The limestone dust is used to fill the voids between the coarse sand grains, and thus to secure at once a minimum surface to be coated, the smallest interstices, and the least per cent of voids.

The proper proportion of pulverized limestone depends upon the fineness of the limestone and of the sand; and the best proportion,

i. e., the one having the smallest per cent of voids, in any particular case can be determined only by trial. To do this, thoroughly mix the sand and the limestone dust in some definite proportion and then determine the per cent of voids in the mixture. To determine the voids, procure a deep and rather narrow vessel, say a tin pail, and find the weight of water required to fill it. Next fill the pail with the mixture of sand and limestone; and then slowly pour in all the water the pail will hold. The weight of water required to fill the pail containing the sand and limestone dust divided by the weight of water required to fill the empty pail is the per cent of voids in the mixture of sand and limestone dust.

The above method of finding the voids is subject to a considerable error, since the water will not expel the air from the sand; and therefore it is better to consider the above only preliminary, and proceed as follows: The sand being dry, fill the pail with the mixture, tamping it as it is put in; and then empty the pail upon a table, taking care not to lose any of the material. Next put into the pail a little less water than is required to fill the voids, and then gradually pour in the mixture previously emptied upon the table, tamping it as it is added. If necessary to keep the mixture wet, add a little more water as the tamping proceeds; and when the material is all in, add water until the pail is level full. Then the total weight of water in the mixture divided by the weight of water required to fill the empty pail is the per cent of voids in the rammed mixture.

The amount of limestone dust ordinarily used varies from 5 to 15 per cent of the sand (see § 625); and the fineness is usually such that all will pass a sieve having 30 meshes per linear inch and at least 75 per cent will pass a sieve having 100 meshes per linear inch.

Table 42, page 413, shows the average fineness of the sand and limestone dust used in the asphalt pavements laid in Washington City by the two paving contractors doing work there, during the year ending June 30, 1897, and also the fineness recommended by Mr. A. W. Dow, Inspector of Asphalt. When available, other asphalt paving contractors use sand and limestone dust of substantially the fineness stated in Table 42.

623. To illustrate the relation between the fineness of the mineral matter and the softness of the asphaltic cement, Mr. Dow cites

TABLE 42.

FINENESS OF THE MINERAL MATTER USED IN THE WEARING COAT OF ASPHALT PAVEMENTS IN WASHINGTON, D. C.*

Ref. No.	Size of Mesh.	Diameter Wire, Inches.	Barber Paving Co.	Crawford Paving Co.	Recommended by Dow.
1	Retained on 10-mesh per linear inch	......	0.0%	0.0%	0.0%
2	" " 20 " " " "	0.017	2.5 "	3.5 "	12.0 "
3	" " 40 " " " "	0.010	24.5 "	27.0 "	25.0 "
4	" " 60 " " " "	0.007	31.0 "	31.5 "	20.0 "
5	" " 80 " " " "	0.005	16.0 "	15.0 "	10.0 "
6	" " 100 " " " "	0.004	11.0 "	10.0 "	18.0 "
7	Passed 100 " " " "	......	15.0 "	13.0 "	15.0 "
			100.0 "	100.0 "	100.0 "

the following examples: † The fineness of the sand in the asphalt pavements laid in Washington in 1894 and 1897 was as below:

	Pavements Laid in 1894.	1897.
Retained on 20-mesh sieve	4.5%	2.5%
" " 40 " "	40.0 "	21.0 "
" " 60 " "	32.0 "	35.0 "
" " 80 " "	9.5 "	8.5 "
" " 100 " "	6.0 "	10.0 "
Passed 100 " "	8.0 "	24.0 "
Total	100.0 "	100.0 "

It will be noticed that the sand used in 1894 was considerably coarser than that employed in 1897. The asphaltic cement used in 1894 was 20° of penetration (Bowen apparatus) harder than that employed in 1897; but nevertheless the 1894 pavements were as soft, and in some cases softer, than the 1897 pavements, as indicated by the tracks left by the traffic.

The Neuchatel rock asphalt (§ 595) is much used in Europe, and has been found to make a hard and durable pavement. This so-called rock asphalt is a limestone powder cemented together by an

* Report of the Operations of the Engineering Department of the District of Columbia for the year ending June 30, 1897, p. 167 and 169.

† Proc. Amer. Soc. of Municipal Improvements, Vol. 5, p. 148.

asphalt "so soft that its flow is perceptible at a temperature of 75° F., which is about three times softer than any asphaltic cement used in the Washington pavements."

624. All asphaltic cements grow harder with age, and are likely to crack in cold weather; and therefore it is desirable to use as soft a cement as possible, a condition which seems to indicate that the sand should be fine. A fine smooth sand requires a considerably harder cement than a sharp angular sand. If the cement is soft and there is a large per cent of voids in the sand, there is a liability that in hot weather the sand will work to the bottom and the asphalt to the top, where it will chip and scale off during cold weather.

625. The Wearing Coat. The asphaltic cement and the sand (or more properly, the mineral matter) are mixed to form the wearing coat. Enough cement should be used to fill the voids in the compacted sand, as otherwise the mineral matter will not be held together with the maximum force; but more cement than enough to fill the voids is objectionable, since the expense is increased, an excess of asphalt causes the wearing coat to flow under traffic during warm weather, and also causes the surface to chip and flake off during cold weather.

In a sense, the purity of the asphalt is not a matter of importance, since the more mineral matter in the asphalt the less the amount of sand and pulverized limestone required. The mineral matter in the asphalt is usually an impalpable powder and is thoroughly incorporated with the bitumen; and therefore it is more desirable than new material. However, since different asphalts differ materially in the amount of contained mineral matter, it is customary to specify the amount of bitumen soluble in carbon bisulphide which the completed pavement shall contain. In southern cities having long hot summers, the soluble bitumen is usually limited to from 9 to 12 per cent; and in northern cities to from 12 to 15 per cent. The exact quantity varies with the amount and character of the traffic, the climate, the fineness of the mineral matter, etc.

Formerly it was customary to state the composition of the wearing surface about as follows: asphaltic cement, from 12 to 15 per cent; sand, from 70 to 83 per cent; limestone dust, from 3 to 15 per cent. The proportions differ considerably with the locality, the

contractor, and the kind of asphalt used. The method of stating the composition in terms of the per cent of bitumen is more exact, and is the form now generally employed.

626. The proportions of the wearing coat are usually stated by weight, while the method of finding the per cent of voids given in § 622 determines the voids in volumes. To determine the proportions by weight proceed as follows: Assume, for example, that it has been found, as described in § 622, that the voids in a mixture consisting of 50 pounds of sand and 5 pounds of limestone dust contain 6 pounds of water; and assume further that the specific gravity of the asphaltic cement is 1.25. The weight of the cement required to fill the voids in the above quantity of sand and dust then is 6 × 1.25 = 7.5 pounds. The proper proportions by weight then are:

Ingredients.	Weight in Pounds.	Proportion in Per Cent by Weight.
Sand	50	82.0
Pulverized limestone	5	8.2
Asphaltic cement	6	9.8
Total	61	100.0

627. Mixing the Cement and Sand. The asphaltic cement and the sand (or rather the sand and the limestone dust thoroughly mixed) are separately heated to 275° to 325° F. The proper amount of cement and sand (§ 626) are weighed out and simultaneously poured into a mechanical mixer consisting of two sets of interlocking revolving blades which thoroughly mix the materials. Usually about 800 pounds of cement and sand are mixed in one batch. When the mixing is completed, a process which ordinarily requires at least 1 to 1½ minutes, sliding doors in the bottom of the mixer are opened, and the material drops out into the carts or wagons which carry it to the street. In this condition, it is a loose pulverulent mass, each grain of sand being very completely coated with the asphaltic cement.

Usually the temperature of each load is taken, and a canvas is thrown over it. The operation of mixing the cement and sand requires care (1) in heating the ingredients to secure a uniform temperature and not to overheat the asphalt, (2) to proportion the mixture accurately, and (3) to mix the materials thoroughly.

628. There is no accurate method of determining whether the asphaltic cement and the mineral matter have been mixed in the best proportions. The only method in use for this purpose consists in compressing a sample of the hot mixture by hand between two sheets of manilla paper or smooth brown wrapping paper, and in noting the mark left on the paper. If the mixture is too rich, the stain will be distinct and blotchy, and some of the cement will stick to the paper; if the cement is just sufficient to fill the voids, the stain will be distinct but not blotchy; and if the mixture is too lean, there will be almost no stain. The test is inexact, since the result depends not only upon the proportion of the cement present, but also upon the temperature and the amount of the pressure. This so-called test is scarcely any better than judging by the general appearance of the mixture. The men employed at the plant soon learn to judge quite accurately of the proportions by the appearance of the material in the mixer.

629. Laying the Wearing Coat. The mixed cement and sand is brought upon the street in wagons or carts, at a temperature of about 280° F. It is dumped upon the binder course (§ 600), and evenly spread over the surface with shovels and rakes. Precautions should be taken that no leaves, straw, pieces of paper, cigar stumps, etc., be mixed with the paving mixture. Great care must be exercised to secure an even distribution of the loose material, as otherwise there will be depressions or elevations in the finished surface. The depth of the mixture is regulated by chalk lines on the curb, by the length of the teeth of the rake, and sometimes by rods supported on feet of a length sufficient to bring the top of the rod to the level of the uncompacted asphalt mixture. The thickness after being rolled varies from 1½ to 2½ inches, and is usually 2 inches. The compression in rolling varies with the richness of the mixture, the leaner mixtures compressing most, but is usually from three tenths to four tenths.

The first compression is given by hand rollers and tamping irons. Two sizes of hand rollers are in use: the lighter is 30 inches in diameter, has a 24-inch face, weighs 1,000 pounds, and gives a pressure of 42 pounds per linear inch of face; the heavier is 28 inches in diameter, has an 18-inch face, weighs 1,400 pounds, and gives a pressure of 77 pounds per linear inch. Fig. 115, page 417, shows

a hand roller with a fire pot inside for heating it. Tamping irons are used around man-hole covers, near the curb, etc., where the

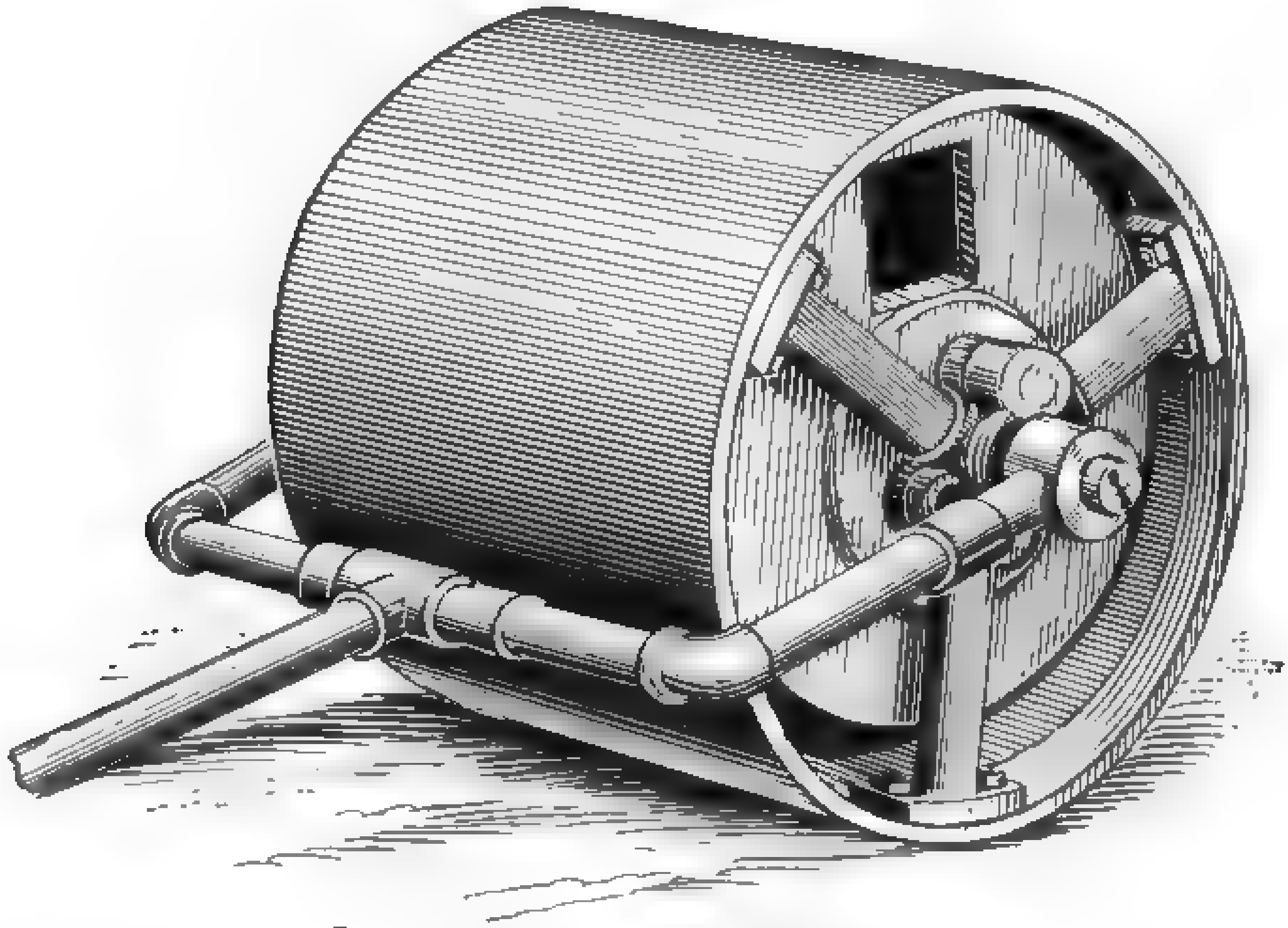

FIG. 115.—HAND ASPHALT-ROLLER WITH FIRE POT.

roller can not be conveniently used. Fig. 116 shows two forms of asphalt tampers. The larger has a face about 8 inches in

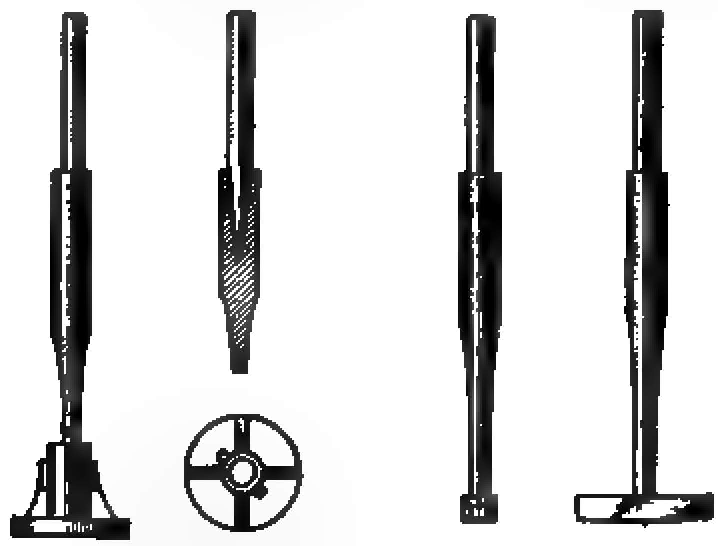

FIG. 116.—TAMPERS FOR ASPHALT PAVEMENTS.

diameter and weighs about 30 pounds; and the smaller has a face about $2\frac{1}{2}'' \times 5\frac{1}{2}''$, and weighs about 18 pounds. The former is used

for general work; and the latter next to curbs, street-car rails, etc. The tamping irons are heated in a fire in an iron basket which is moved from place to place on wheels. The original method of compression was first to run a hand roller (whose surface was prevented from taking up any of the sticky mixture by being oiled with kerosene) rapidly over the surface, four men being employed for this work. This method is still employed to a certain extent, but it has been improved upon and superseded in part by a form of roller which is attached to the front of the steam roller, and which is heated by steam. It is guided by a parallel motion from the steering gear of the steam roller and does away with the necessity of any one's walking on the newly laid surface.

After the first compression with hand rollers and tampers, men with hot tamping and smoothing irons, Fig. 116 and 117, proceed

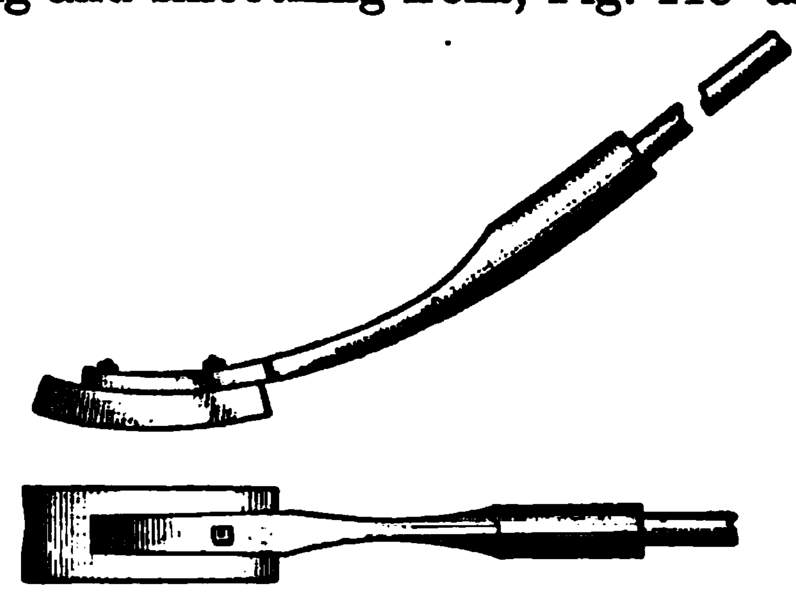

FIG. 117.—ASPHALT SMOOTHING IRONS.

to finish the gutters, joints, and all angles and edges which can not be reached with the heavier rollers. The gutters are tested with straight edges to detect depressions, and any inequalities on the surface are removed. The use of hot smoothing irons and hot rollers should be discouraged, since it is impossible always to have them of such a temperature as not to injure the pavement, and since, if the mixture is delivered at the proper temperature, and the raking and spreading is done expeditiously, they are unnecessary. Experience shows that the surface of pavements upon which hot smoothing irons were used scales and flakes off, while the surface of pavements laid without such hot tools does not chip and scale off.

The first compression having been given, some natural hydraulic cement or any impalpable mineral matter is dusted over the surface

to give it a more pleasing color and to prevent adhesion of the roller; and then the surface is next rolled with a steam roller of the asphalt pattern (Fig. 65, page 225). In the most approved method the pavement is first rolled with a roller weighing about 5 or 6 tons, and next with a roller weighing 10 or 12 tons. Often only the light roller is used. If the street is wide enough, the pavement should be rolled transversely as well as longitudinally; and if this is not possible, the roller should run as obliquely as possible, so that any little inequality which might be caused by the roller's moving lengthwise may be taken out by the cross action. The rolling should be kept up until the roller leaves no mark, a result which usually requires at least 5 hours for each one thousand square yards of surface.

The rolling should closely follow the spreading of the material, so that it shall not have time to cool before the final compression is obtained. The state of the weather also is an element to be considered; for if a strong wind be blowing, the material, spread over a broad surface only 2 or 3 inches thick, will cool much more rapidly than on a calm day when the temperature is considerably lower.

When the rolling is completed, the pavement may be thrown open. Traffic, if not of too heavy vehicles, is an advantage to a newly laid asphalt pavement, since the pressure of the wheels aids in consolidating the wearing coat and in closing the surface, a result which helps to retain the volatile oils and prevents the entrance of water. Asphalt pavements in unfrequented streets do not wear so well as under a moderately heavy traffic.

630. The top of the binding course should be perfectly dry when the wearing coat is laid, to prevent its being separated from the course below by the formation of steam. Asphalt should not be laid in cold weather, since the paving mixture may become chilled between the mixing plant and the street, and particularly when it comes in contact with the cold foundation.

The chief points requiring skill in the working of the asphalt surface are: (1) in avoiding inequalities of the surface, especially depressions which prevent the rapid removal of storm water; (2) in securing a very thorough consolidation of the gutters, which otherwise rot rapidly; and (3) in thorough rolling. The asphalt mixture can not be fully compacted by simple pressure, but requires the kneading action of repeated passages of the roller. The lubricating quality

of the warm asphalt aids in this action, so that under the roller the grains of sand are wedged together and the finer particles worked into the voids, until the mass becomes more dense than dry sand alone could be made. This is proved by the fact that if all the bitumen be extracted from a fragment of pavement of known volume, it is found to be quite impossible to reduce the dry sand obtained to as small a volume as it occupied in the pavement.

On streets with flat grades the gutters do not drain well; and as moisture is likely to injure asphalt, the gutter is painted with a coat of hot asphalt or is laid with hydraulic cement concrete, stone, or brick. If the gutter is fairly well drained, and the asphalt is thoroughly compacted, the first method will give reasonably good results. The gutter may be painted with a swab or a broom; but the work is most easily done with a gutter painter, which consists of a cast-iron box about 14 inches square having a slot in the bottom, carried by a rigid handle on each side.

To protect the asphalt along street-car tracks and sidewalk crossing-stones, where there are vibrations and pounding of the wheels of vehicles, it is customary to lay a line of granite blocks or vitrified blocks—usually headers and stretchers alternately. The toothing of the bricks or the stone blocks into the asphalt adjacent to car tracks, gutters, etc., is to do away with the continuous joint and thus to prevent wheels from wearing a rut; but there is so much difficulty in sufficiently compacting the asphalt between the projecting blocks, that the toothing is of doubtful value. After several years' trial it has been abandoned in Washington, D. C.

631. Causes of Failures of Asphalt Pavements. Asphalt pavements have frequently failed; but when it is remembered that the industry is new and has been rapidly developed, and that there was no precedent, and that therefore the proportions and the methods of mixing and laying had to be determined by actual experience, it is not astonishing that some pavements should fail. But the permissible variation in the various ingredients and in the different details of the work is so small, that if good results are expected, the utmost care must always be exercised. Asphalt pavements have some advantages not possessed by any other forms of pavement, and will doubtless always be laid to a considerable extent. Therefore the engineer who is responsible for such work should be well

informed as to the various steps in the construction of this class of pavements.

Unfortunately the custom has been to contract with asphalt paving companies to lay asphalt pavements and to guarantee them for a term of years, and consequently the municipalities have as a rule made no analysis of either the asphalt or the flux used, and have not examined the sand or limestone dust nor paid any attention to the methods employed in mixing and laying the materials. The result is that there are no public records showing the history of the pavement, and therefore it is often impossible to determine the cause of either failure or success. City officials should carefully analyze the ingredients and examine the method of mixing and laying the materials, not only to secure the best possible pavement, but also to obtain data to serve as a guide for similar work in the future. Owing to differences in materials, climate, and traffic, a considerable part of such data must be obtained for each particular city.

On account of the lack of such data, it is often impossible to determine certainly the cause of the failure in any particular case. The following are some of the principal causes of the failure of asphalt pavements:

632. Unsuitable Material. The service demanded of a pavement is quite severe, and to attain a reasonable success each of the three components—the asphalt, the flux, and the sand—must be carefully selected.

633. *Asphalt.* The asphalt may have been so changed by natural causes as to possess little or no cementing power (see § 649); or it may have contained a soluble salt which was subsequently dissolved by rain water, thus leaving the pavement porous and subjecting it to the disintegrating effect of the acids and oxygen in the rain water as well as to the effect of the freezing of the water in the pores of the pavement.

If the asphalt is deficient in cementing power or is unduly disintegrated by the action of acids, oxygen, etc., this fact will generally first be indicated by a premature tendency of the pavement to crack, particularly during cold weather (see § 654).

634. *Flux.* The fluxing agent may not have been a solvent of both of the constituent parts of the bitumen of the asphalt, and may

have formed a mechanical mixture instead of a chemical union (see § 604). Or the flux may have contained volatile oils which finally evaporated from the pavement and left it porous and devoid of cementing power (see § 604). The use of an improper fluxing agent will produce much the same effect as an asphalt deficient in binding power (§ 586).

635. *Sand.* The sand may have been too coarse, or too fine, or have contained too much clay or vegetable matter (see § 621–24). If the sand is too coarse, or is dirty, the pavement will have a tendency to crack. If the sand is too fine, or is deficient in sharpness, the pavement will have a tendency to roll or push out of place—particularly under a heavy traffic,—and the surface may be marked by the traffic in hot weather.

636. *Free Oil in Binder.* The binder may contain an oil which will subsequently be absorbed by the wearing coat and cause the asphalt to disintegrate. This is more likely to occur with a coal-tar than with an asphalt binder. Pavements affected this way give signs of disintegration by a slight depression over the affected spot, and in time numbers of small cracks appear, running parallel with the street, which gradually increase in prominence, accompanied with transverse cracks, until the pavement has the appearance of alligator skin.

637. Improper Manipulation. Even though the materials may be the best, there is an abundant opportunity for failure through improper manipulation in heating and mixing the materials.

638. *Too High Heat.* The asphalt may have been damaged by overheating or "burning." The burning of the asphalt causes the pavement to disintegrate on the surface in spots during cold weather, and may be revealed by a brittleness and a tendency to crack while being rolled. Excessive heat converts the petroline, or cementitious constituent of asphalt, into asphaltine which is devoid of cementing properties, and by so much reduces the cementing quality—the vital element—of the asphalt. This overheating may take place during the refining (see § 590), or during the fluxing (see § 609), or in mixing the asphaltic cement and the sand (see § 627).

In practice there is much carelessness in melting the asphalt. Not infrequently the kettle is mounted within brick walls directly

over a fire which comes in contact with only a comparatively small part of the heating surface, in which case it is highly improbable that the firing will be done so evenly and slowly as not to burn at least part of the material. The fire should not be allowed to come in direct contact with the melting kettle or tank, thereby guaranteeing that no portion of the asphalt can be burned. When the asphalt has been badly burned, it will be revealed by a brittleness during rolling; but there is no way of determining a lesser degree of burning, although it still may be sufficient to cause a serious defect which will finally develop into cracks and rotten spots. Therefore the inspector should insist upon a method of melting that will insure an unburned product. It is sometimes specified that the asphalt shall be heated by steam.

The overheating of the asphalt may be produced also by overheating the sand (see § 627). Every precaution should be used to have each batch of sand heated uniformly throughout, and its temperature should be taken before mixing it with the asphalt. As a further check, the temperature of each load of paving compound sent to the street should be taken and recorded at the mixing plant.

639. *Improper Consistency.* The paving cement may have been mixed too hard or too soft (see § 613). If the cement is too hard, the pavement will have a tendency to crack during cold weather; and if it is too soft, it will push out of place and form rolls or waves under the traffic.

640. *Insufficient Bitumen.* The wearing coat may not have contained sufficient cementing material. It should contain at least 9 per cent of bitumen soluble in carbon bisulphide (see § 611). Within the limits imposed by the proper softness and hardness of the pavement, the greater the per cent of asphalt the greater the life of the pavement; and consequently contractors in laying a pavement under a long-time guarantee use the maximum amount of asphaltic cement, but when the maintenance period is short they generally use the minimum. Owing to improper manipulation the amount of bitumen is likely to be too small, since in fluxing the tendency is for the bitumen to rise and the mineral impurities to settle; and consequently if the tank is worked too low, there is a likelihood that the last material taken from the tank will contain too small a pro-

portion of bitumen and too large a proportion of sediment. Insufficient bitumen has substantially the same effect upon the pavement as improper asphalt.

641. *Inadequate Mixing.* The ingredients of the wearing coat may not have been sufficiently mixed. It is important that each grain of sand shall be entirely surrounded by the cementing material, so that no two pieces shall come into actual contact. If the mixing is not well done, the pavement will disintegrate in spots.

642. *Rich Binder.* If an excess of asphalt or coal is used in the binder course, it is likely to work to the surface of that course and then being absorbed by the wearing coat cause it to disintegrate. This cause of failure manifests itself by irregular blotches on the surface of the pavement.

643. *Cement Chilled.* The mixture for the wearing coat may become chilled while being transported from the mixing plant to the street. To prevent this possibility, the temperature of each load should be taken just before it is laid. The material may also become chilled by a delay in tamping and rolling, or by attempting to work during too cold weather or during the prevalence of a high wind. A batch of chilled mixture will cause a weak spot in the pavement.

644. *Separation of Cement and Sand.* If the distance from the plant to the street is long or there is unusual delay, some of the asphaltic cement may work down to the bottom of the load, and when the material is dumped there will be both rich and lean spots —both of which are equally objectionable. The rich spots will have a tendency to roll or crowd toward the gutter; and the lean spots will have a tendency to disintegrate under traffic.

645. *Damp or Dirty Foundation.* The wearing coat may have been laid on a dirty or damp foundation, and therefore have been prevented from uniting firmly with the foundation (see § 598). This condition will be revealed by a tendency of the pavement to roll or push out of place while sound and firm on the surface.

646. *Inadequate Compression.* The wearing coat may not have received sufficient compression. The surface must be thoroughly compacted—particularly in the gutters—to keep out rain water and the acids and oxygen dissolved in it. The effect of oxidation is gradually to convert the petroline into asphaltine, and to leave

the bitumen of the flux as the only binding constituent of the mixture; and therefore the pavement will have a general tendency to crack and disintegrate.

647. Natural Causes. All materials in nature are undergoing changes due to the action of the elements, and asphalt pavements are no exception. The following are some of the principal causes leading to the gradual deterioration of such pavements.

648. *Ordinary Wear.* The pavement may decrease in thickness due to loss of material by the abrasion of hoofs and wheels; but since the surface is smooth and somewhat elastic the loss by wear is almost imperceptible. In come cases the pavement decreases in thickness with use, but the decrease is due to consolidation rather than to loss of material.

649. *Natural Decay.* All asphalts gradually lose their cementing power with age by volatilization, evaporation, and oxidation. The pavement is peculiarly exposed to the action of the sun's heat, and to the combined action of rain water, acids, oxygen, and frost. The greater the cementing power of the asphalt originally and the softer the cement, the longer the pavement will resist the influence of volatilization and evaporation; and the more nearly the voids of the sand are filled with cement and the more firmly the pavement is consolidated, the longer it will resist the action of water, acids, oxygen, and frost. The general decay of the asphalt will be indicated by a tendency of cracks to form during cold weather (see § 654), particularly during a sudden and extreme drop in the temperature.

650. *Weak Foundation.* A weak or improperly prepared foundation by unequal settlement or settlement in spots will cause cracks and depressions in the surface which under traffic will speedily enlarge and cause the pavement soon to break up.

651. *Porous Foundation.* A porous foundation permits the ground water to rise, by capillary action and possibly also by hydrostatic pressure, to the underside of the wearing coat, where by freezing it may break the bond between the top layer and the base, and thus permit the wearing coat to be pushed out of place and broken. This effect has been known to occur with a concrete foundation; but it is not likely to occur with good concrete. If a section of pavement disintegrating from this cause be examined,

there will be found a layer of perfectly sound and good material at the surface, while the lower side of the wearing coat will show evidence of being disintegrated by water—that is, the sand will appear clean and white in spots as though there had been an insufficiency of asphalt cement to cover it. The concrete base under the affected spot will generally be found to be damp or even wet. The recurrence of this defect may be prevented by underdraining the soil.

652. *Leaky Joints.* Lack of a water-tight joint between the asphalt surface and the curb, the gutter, manhole covers, crossings, street-car rails, etc., may permit the water to enter the lower and less compact part of the wearing coat, where by its solvent action and also by freezing it may do material damage. It is nearly impossible to keep these joints tight, particularly adjacent to the street-car rails. The damage often extends a considerable distance from the place where the water enters.

The disintegrating effect of water depends chiefly, if not wholly, upon the contained oxygen, and the effect upon different asphalts varies with the proportion of soluble salts present. Apparently Trinidad asphalt is acted upon to a greater extent by water than any other asphalt;* but it is claimed † that this deterioration can be greatly reduced by removing the soluble salts in the refining process, at a comparatively small expense. For the results of experiments showing a great variation in the effect of water and of frost upon different asphalt pavements, see *Engineering News*, Vol. 44, p. 113–15. In these experiments, two samples of asphalt blocks lost considerably less than any one of the seven samples of sheet asphalt.

653. *Illuminating Gas.* Ordinary illuminating gas, escaping from leaky pipes under the pavement, is absorbed by the pavement, and causes the disintegration of the asphalt.‡ It has been determined experimentally that "one volume of asphalt cement will

* The Action of Water on Asphalt, by George C. Whipple and Daniel D. Jackson. A paper read before the Brooklyn (N. Y.) Engineers' Club, March 8, 1900; and published in *Engineering News*, Vol. 43, p. 187–88.

† A. W. Dow, Inspector of Asphalts, Annual Report of Operations of Engineering Departemnt of the District of Columbia, 1901, p. 156.

‡ For the results of a very careful investigation of this subject, see a report by A. W. Dow, in Annual Report of the Operations of the Engineering Department of the District of Columbia for the year ending June 30, 1899, p. 111-112.

absorb forty-five volumes of illuminating gas in something over a month; and it has been demonstrated practically that pavements do actually absorb illuminating gas from leaky mains, in one instance 1,000 c.c. of pavement giving off 500 c.c. of gas which it had absorbed. It has been shown that asphalt is much softened by absorbing gas, the ordinary asphalt becoming as soft as maltha after being in an atmosphere of illuminating gas for several months. There is but one way to stop the disintegration of a pavement from this cause, and that is to stop the leak of gas."*

Pavements affected by illuminating gas first give signs of their disintegration by a slight depression over the affected spots, later fine cracks appear parallel to the line of the street, and finally the surface coat begins to crowd.

654. *Cracks.* Long irregular cracks in the wearing surface frequently occur during cold weather. They usually start at the gutter or man-hole frame, and gradually extend across the street. They are often found at the joint between an old and a new pavement or at the joint made between one day's work and another. These cracks are due to the contraction of the wearing surface, and should not be confounded with cracks due to the failure of the foundation (§ 650). Usually these cracks do not occur until the pavement is two or three years old; at least they are most likely to occur in an old pavement—one in which the asphalt has lost part of its cementing power by age. These cracks appear sooner and increase more rapidly on a street having only a light traffic. When the pavement is subjected to a continuous traffic, the asphalt surface, which is more or less plastic at all temperatures, is kept from cracking by the constant kneading action of the traffic. Again, when an asphalt surface has but little or no traffic, it becomes more porous owing to expansion and contraction from heat and cold without the compression due to traffic, and as a consequence is materially weakened. If cracks occur on a street having a fair amount of traffic, it is evident that the paving mixture used is at fault; either there was not enough bitumen or the asphalt cement was too hard.

*A. W. Dow, in Annual Report of the Operations of the Engineering Department of the District of Columbia, 1899, p. 112.

Some engineers leave expansion joints, i. e., cut the wearing coat through, at intervals to prevent these irregular contraction cracks. Such a procedure is of doubtful propriety, since the pavement if properly constructed will not crack in several years under the most adverse conditions, and then only at long intervals and generally at some old joint; and if the pavement is improperly made, the expansion joint will have only a slight tendency to prevent these irregular cracks. The principle of the expansion joint is not applicable to materials with no structural strength, like asphalt mixtures. These joints are not only useless, but really detrimental to a pavement; they are only another form of the defect they are intended to remedy, for they are crevices which retain mud and water which tend to rot the asphalt, and the edges of the joints are easily broken down by traffic which also widens the crack.

It is particularly unfortunate that an asphalt pavement is likely to crack, since not only do the edges of the cracks disintegrate, but the cracks permit water to reach the interior of the pavement where it has a deteriorating effect.

655. *Shifting under Traffic.* The surface coat sometimes flows under traffic, i. e., pushes lengthwise of the street into waves or crowds toward the gutter. This defect occurs in pavements having too soft a wearing surface, or where there is a defective bond either between the base and the binder, or between the binder and the wearing surface. This is a defect that is impossible to guard against entirely on a street having very heavy traffic, and especially where the traffic is confined to a narrow section of the street; but this defect is inexcusable on streets having only moderately heavy traffic. This flowing is commonly caused by the surface of the hydraulic concrete base under the pavement being too smooth, which is the case where gravel concrete is used or where a stone-and-gravel concrete is so rich that its surface is covered with mortar that was brought to the top by ramming. Unless the binder and the surface mixtures are made very hard, a condition which makes the pavement likely to crack, the wearing coat will slide on such a base if there is much traffic. Pavements often roll from a defect in the binder—either because it was too rich in asphaltic cement, or because it was dirty when the wearing surface was laid.

656. *Damage by Bonfires.* Another cause of damage to asphalt

pavements is the building of fires upon them. Of course this ought never to occur, but even in the best regulated municipalities it does happen.

657. METHOD OF REPAIRING. The repairs necessitated in the maintenance of an asphalt pavement may be classified as follows: (1) those due to a settlement of the subgrade; (2) those due to a disintegration of the pavement in spots; (3) those due to the formation of waves; (4) those due to the formation of cracks; (5) the painting of the gutter; and (6) the remedying of defects next to the street-car rails, crossing stones, man-hole covers, etc.

658. Settlement of Subgrade. It is generally conceded that the majority of repairs are necessitated by the settlement of the foundation over trenches. To repair these defects, it is necessary to remove the wearing coat, the binder, and the foundation, and then, after having consolidated the material in the trench (see § 450), to relay the pavement much as in the original construction. The edges of the binder course and also of the wearing coat should be thoroughly covered with a thin coat of asphaltic cement to secure a perfect union of the old and the new material. The stone in the old concrete should not be used again, since the mortar makes a surplus of fine material and would prevent a firm adhesion of the new cement to the stone. Both the binder course and the wearing coat should be thoroughly tamped or rolled. Owing to the difficulty of fully consolidating the patch, it is left a trifle high to prevent a possible depression.

659. Disintegration in Spots. If the wearing coat disintegrates in spots, or forms "macaroons," from any of the causes described in § 631–53, the affected part must generally be cut out, since it is usually affected to its full depth. If the binder course is the cause of the deterioration (see § 642), it also must be cut out. The new material is to be laid as described in the preceding paragraph. If the disintegration does not extend to the full depth of the wearing coat, the repair may be made by "skimming," as described in the succeeding paragraph.

660. *Formation of Waves.* If the wearing coat has shifted under the traffic so as to form waves, i. e., until it is thicker in some parts than others, or if the wearing coat has crowded towards the gutter, it may be necessary to melt off a portion of the high part, and also to

re-surface the thin part. This is called skimming. The asphalt is melted off either with an open grate on low wheels in which coke is burned; or with a special heater having a tank for gasolene, a hood over the burner, and an asbestos mat to protect the adjacent pavement. Fig. 118 shows the form of surface

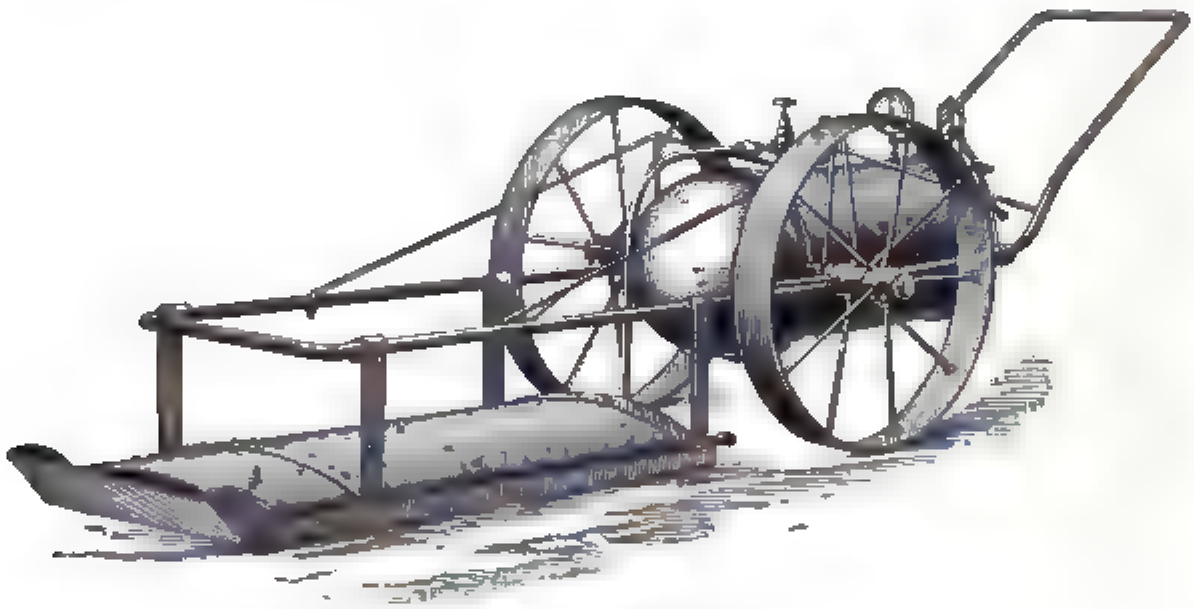

FIG. 118.—SURFACE HEATER FOR REPAIRING ASPHALT PAVEMENTS.

heater in common use. The surface is heated until the affected portion can be raked off; and then new material is added to bring the pavement to its proper thickness. There is considerable difference of opinion as to the possibility of doing good work by this method.

661. Cracks. When cracks have formed in the wearing coat, all the loose material is cut off, the crack is cleaned out, and hot asphaltic cement is poured in.

662. Painting Gutters. Owing to the disintegrating effect of water, asphalt gutters usually require comparatively frequent repairs either by painting (§ 630) with asphalt rich in bitumen, or by skimming (§ 660), or by removing the wearing coat and re-laying it, using an asphalt richer in bitumen than that in the remainder of the pavement.

663. Recording Repairs. The present practice is to make the repairs to asphalt pavements by contract with a guarantee of the work for a number of years; and therefore it is important that a record should be kept of the area and location of the several patches

and also of the date when each was made. This is done by dividing the pavement into imaginary squares, of say, 10 feet on a side; and then when a patch is to be made, one or more of these squares should be located by chalk marks on the pavement, and the boundary of the patch should be sketched in a cross-ruled note-book. The records of the individual patches are afterwards platted upon a single sheet to see that a subsequent patch does not overlap one for which the guarantee has not expired.

664. Using Old Materials. In some cities it is customary to permit the re-use of the old asphalt, but this is of doubtful wisdom, since usually the repair is required by the inferiority of the old material, and since it is likely to be over-heated in being removed. If the asphalt is not damaged, and is cut out with an ax, it may be used again, provided (1) the pieces are kept clean, (2) it is reheated slowly and carefully, and (3) new asphalt is added to flux the old. It is difficult to melt old material without burning it, and it is also difficult to secure a uniform mixture.

665. Specification for Repairs. Asphalt pavements are usually maintained by contract, and therefore it becomes important to have some standard, particularly at the end of the contract period, by which to judge of the liability for repairs. The following specifications have been recommended for this purpose by a committee of the American Society of Municipal Improvements.*

"Sec. 1. The pavement shall not be reduced more than one fourth inch from the original thickness at the end of the first five years, or more than one half inch from the original thickness at the end of the first ten years. (This requirement shall not apply to pavements constructed of rock asphalt, as this material does not receive its ultimate compression for a considerable period after being laid.)

"Sec. 2. Places which show a disintegration of the material shall be removed to the binder or concrete foundation, as found necessary, and be replaced with new material having the same thickness and conforming to the adjacent pavement.

"Sec. 3. All elevations or depressions three eighths of an inch or more above or below the general surface of the street shall be brought to the same elevation as the general surface, these elevations and depressions to be determined by measuring from a straight edge four feet in length, placed on the

* Proc. Fourth Annual Convention (1897), p. 142–43.

surface of the pavement parallel to the line of curbing.* (In making such repairs the process known as "skimming" may be employed)

"Sec. 4. Where elevations or depressions are due to the failure of the concrete foundation from any cause, the asphalt and concrete shall both be removed a length and width to include the entire defect. If the failure is due to buckling of the concrete, the new foundation shall consist of broken stone thoroughly compacted, and of the same thickness as the original concrete. In all other cases a new foundation of concrete shall be placed of the same thickness as the original construction. Upon the foundation shall be placed a pavement of the same thickness as the adjacent surfaces.

"Sec. 5. Cracks which show any indication of disintegration, or which are three eighths of an inch or more in width, shall be cut out to the binder or concrete foundation, as found necessary, a length and width sufficient to include the entire portion affected; and this portion shall be replaced with new material of the same quality and thickness as in the pavement adjacent thereto.

"Sec. 6. Should it be found necessary to replace twenty-five per cent or more of any section of the street with new material, the entire section shall be re-surfaced."

666. COST OF SHEET ASPHALT PAVEMENTS. Any general statement of the cost of any engineering construction can be only approximately true in in any particular case, owing to variations in local conditions, the prices of material and labor, etc.; and any accurate statement concerning the cost of asphalt pavements is rendered still more difficult by the existence of artificial conditions which control prices, and also by the fact that the public has little or no reliable information as to the actual cost of laying asphalt pavements. During the early history of the asphalt paving industry, a single company imported and in its own name constructed nearly all the asphalt pavements laid in this country, using exclusively asphalt from the island of Trinidad. Later this company obtained an almost complete monopoly of this asphalt. It is claimed, apparently with justification, that this company then organized a number of subsidiary companies, and that for a number of years thereafter there was practically no competition in the asphalt paving business, except in name. Later the discovery of other sources of supply developed competition; but before many of the competing companies had gained commercial experience

* In Berlin, Germany, the requirement for rock asphalt pavement is 15 mm. (0. 6 inch) under a straight edge 1 meter (3.28 feet) long.

and technical knowledge to enable them to compete upon an equal footing with the parent company and its auxiliaries, a new combination, or "trust," was formed. Consequently during but little, if any, of the history of the asphalt paving industry in this country has the unfettered law of supply and demand acted to establish prices.

Another reason why current prices for asphalt pavements are less instructive than those for other forms is that it is customary to include in the contract price of asphalt pavement the maintenance for a term of years, varying from 5 to 15; while maintenance is usually not so included with other forms of pavements. The proportion of the original contract price required for maintenance will vary with the local circumstances, particularly with the climate, the amount and the nature of the traffic, the width of the street, and the presence or absence of street-car tracks.

667. Cost of Asphalt. The real value of asphalt for paving purposes depends upon the per cent of contained bitumen soluble in carbon bisulphide; and consequently when a price of asphalt is given a statement should also be made of the per cent of soluble bitumen present. In the days of freest competition, the price of Trinidad asphalt in the cities on the Atlantic coast of the United States governed the price of all asphalts for that part of the country east of the Rocky Mountains.

The estimated cost of Trinidad asphalt in New York City is as follows: *

Digging, transferring to vessel, and loading, per long ton	$1.60
Royalty on asphalt from government lands, per long ton	.40
Export duty, per long ton	1.20
Freight and insurance to New York	2.00
Unloading	.50
Cost of crude asphalt, per long ton	$5.70
Cost of refining, allowing 30 per cent loss	2.50
Cost of about 1,568 pounds of refined asphalt	$8.20
Cost of refined asphalt per short ton	$10.49

The lowest market quotations for refined Trinidad asphalt, which contains about 53 per cent of bitumen soluble in carbon bisulphide (Table 40, page 393), of New York City have

* Report of Commissioners of Account of the City of New York on Asphalt Paving, May 9, 1899, p. 33–37.

been $30 to $35 for 1,880 pounds net, or about $35 to $42 per long ton net. It is claimed * that the selling price in European sea ports for a number of years past has been about as follows: crude $10.34, refined $17.54, per long ton, net. It is also claimed † that the above estimates are corroborated by the prospectus issued by the London Company and verified by the certificate of Chartered Accountants. The difference in price between the two sides of the Atlantic is probably due to the fact that in Europe there is less demand for asphalt pavements (see § 597) and more competition in rock asphalts; while in this country there is, or at least was formerly, a general belief that Trinidad lake asphalt makes a better pavement than asphalt from other sources.

668. Cost of Construction. Asphalt pavements are comparatively expensive, since the tools and machinery employed in mixing and laying the asphalt are costly and subject to large depreciation whether idle or in use, and also since the business requires a considerable proportion of skilled labor. One of the peculiarities of the business is the disproportionate amount of capital invested in the plant compared with the business done, often an expensive plant being maintained in a city for one or more years without laying any pavement or at most only a comparatively small amount. Another peculiarity is that the working season is short, extending only from, say, the first of May to the first of November; and as expert superintendents and foremen are indispensable, it is necessary to employ this skilled labor by the year.

The estimate of the cost of laying an asphalt pavement shown in Table 43 was prepared for this volume by a man of acknowledged ability and unquestioned integrity, who has had 15 to 20 years' experience in the administration of asphalt paving business in various cities, but who at the time of making this estimate had no financial or other interest in such matters. The estimate is for a city in which 20,000 square yards are laid in one year.

* Report of Commissioners of Account of the City of New York on Asphalt Paving, May 9, 1899, p. 34.

† *Ibid.*, p. 36–37.

TABLE 43.

ESTIMATED COST OF LAYING ASPHALT PAVEMENT.

Plant and Capital Charges:			
Interest on cost of fixed plant,—5% of $13,500	$675.00		
Interest on cost of rollers, tools, etc.,—5% of $3,000	150.00		
Taxes,—2% of $10,000	200.00		
Insurance,—4% of $10,000	400.00		
Depreciation,—8% of $16,500	1 320.00		
Rental or interest on real estate,—7% of $4,000	280.00		
Interest for 6 mo. on working capital,—5% of $6,000.	150.00		
Current repairs	300.00		
Watchman for 1 year	300.00		
Total for 20,000 sq. yds	$3 775.00		
For 1 square yard			0.189
Local Management and Clerical Expenses:			
Rent of office 1 year	$400.00		
Telephone, light, water, etc	100.00		
Salary of Superintendent for 6 months	1 000.00		
Cashier in charge of office—6 months	600.00		
Clerks, time keepers, etc.—3 months	360.00		
Proportionate part of winter pay roll	750.00		
Total for 20 000 sq. yds	3 210.00		
For 1 square yard			0.16
General Officers and Offices:			
Laboratory and general expenses			0.20
Expense Securing Contracts:			
Agent's commission, legal and traveling expenses, etc			0.12
Material and Labor per Sq. Yd.:			
Subgrade,—0.25 cu. yd. grading, rolling, etc		.125	
Foundation,—6 inches of concrete (1 N. C. : 2 S. : 4 B. S.).		.48	
Binder,—1 inch complete		.17	
Wearing coat,—2 inches:			
40 lb. refined Trinidad asphalt at $30 per ton		.60	
0.75 gal. residuum oil at 6c		.045	
0.083 cu. yd. sand at $1.20		.10	
16 lb. pulverized limestone at $3.50 per ton		.028	
Fuel used at plant		.029	
Oil, waste, and sundries		.002	
Labor at plant		.073	
Hauling material to street		.03	
Laying and rolling		.075	
Total for materials and labor			1.757
Cost of Guarantee:			
5 years at 2½ cents per year			.125
Total cost of pavement, per sq. yd			$2.551

669. Of course the cost will vary slightly in different cities; but the estimates in Table 43 are intended to be fair averages. The figures for cost of materials and labor are averages of data from actual work, and include transportation and loss by tare, waste, etc. For example, while the actual quantity of asphalt in a square yard of pavement is about 32 pounds, 40 pounds must be purchased, since the tare (weight of barrels and of asphalt adhering to them) is 12½ per cent; and the loss through evaporation, sedimentation, skimming and waste is 7 or 8 per cent more.

Not infrequently in recent years have prices been obtained considerably less than the estimate in Table 43. For example, during the years 1895–98, when the competition between the various asphalt paving contractors was very sharp, bids were received in several widely separated cities as low as $1.40 to $1.50 for nominally the same pavement as in Table 43. It should be stated, however, that the above were years of great industrial depression, and consequently wages were low and there was less paving in progress than usual. The asphalt paving contractors explain this discrepancy by saying that their plant and organization subject them to large fixed charges whether or not they do any work, and that therefore it is better to keep the men and plants at work at any price that leaves a little margin above actual cost of materials and labor. The asphalt paving contractors claim that contracts have sometimes been taken at a loss to drive competitors from the field; and also claim that many of the smaller asphalt companies actually lost money in their business, and continued in the field only because they hoped to compel their more successful competitors to buy them out. It is further claimed that if the contractor is less careful of the quality of his work, the price can be materially reduced, since a less expensive plant may be employed and no permanent organization would be maintained. The estimates in Table 43 contemplate first-class work in every particular; but of course if a lower grade is sufficient, the price may be lessened by reducing the quantity and quality of the concrete, the thickness and quality of the wearing course, the amount of rolling, the care employed in forming a true surface, etc. Table 44, page 438, shows the average prices paid in forty-five cities during the year 1900, and also gives some of the details concerning the

method of construction and the cost of materials, labor, etc. Notice that the prices in Table 44 do not include grading, i. e., include only the concrete base, the binder, the wearing coat, and a 5-year or a 10-year guarantee; while the cost of the corresponding items in Table 43 is $2.43 for a 5-year guarantee and $2.55 for a 10-year guarantee. In Washington, D. C., the maximum price is limited by act of Cougress to $1.80 per square yard for a 1½-inch wearing coat, a 1½-inch binder course, a 6-inch concrete base (1 N. C.: 2 S.: 5 B. S.), and a 5-year guarantee.

670. Cost of Maintenance. The cost of maintenance will vary with the original quality of the pavement, its age, the amount and nature of the traffic—the cost under either very heavy or very light traffic being greater than that under moderate travel,—the width of the street, the presence or absence of street-car tracks, the frequency with which the pavement is cleaned and sprinkled, the climate, etc. Owing to the marked influence of some of these elements, and to the usual lack of definite data concerning the most of them, it is impossible to give data of any considerable general value.

Table 45, page 440, gives the cost of repairs of asphalt pavements in Buffalo, N. Y., a city that until recently had more such pavements than any other city in the world. An inspection of the table shows a marked variation in the cost of repairs from year to year. The results for pavements laid in 1883, 1885 and 1886 are abnormally high, a fact which shows that considerable poor work was done during those years.

Table 46, page 441, gives data on the cost of repairs of asphalt pavements in Buffalo on residence and business streets with and without street-car tracks. Notice that the cost on business streets increases each successive year, while that for residence streets as a rule decreases after the sixth year. The first result is what would be expected; but no satisfactory explanation has been found for the anomaly of the second result. Notice also that the cost on residence streets is more with street-car tracks than without them, a condition which is contrary to ordinary experience. Both of the above anomalous results are doubtless due to poor work or to excessive travel on one or more of the streets.

TABLE 44.

AVERAGE COST OF ASPHALT PAVEMENTS IN 42 CITIES IN 1900, INCLUDING ONLY BASE, BINDER, AND WEARING SURFACE.
Compiled by F. V. E. Bardol, Chief Engineer, Buffalo, N. Y.,—see Report of Board of Public Works for 1900, Table C, p. 68.

Ref. No.	Cities.	Average Price per Sq. Yd.	Guarantee Years.	Foundation.			Cost of Foundation Materials.				Asphalt.		Hours per Day.	Wages per Day.
				Thickness.	Proportions.	Kind of Cement.	Cement, *bbl.*	Sand, *cu. yd.*	Bk. St., *cu. yd.*	Con-crete, *cu. yd.*	Thickness Binder.	Thickness Topping.		
1	Altoona, Pa.	$2.47	5	6	1 : 2 : 5	Nat.	$0.80	$1.55	$1.68	$4.20	1	1½	10	$1.60
2	Atlanta, Ga.	2.83	10	6	1 : 2 : 4	"	1.00	.75	1.25	4.50	1½	1½	10	1.00
3	Baltimore, Md.	2.18	5	6	1 : 3 : 5	"	1.00	.75	1.50	3.30	1½	2	8	1.66
4	Boston, Mass.	3.25	10	6	1 : 3 : 7	Port.	2.50	1.30	1.70	4.50	1½	1½	9	1.75
5	Brooklyn, N. Y.	3.15	10	5	1 : 3 : 6	"	2.20	.77	1.60	5.63	1	2	8	1.50
6	Buffalo, N. Y.	2.20	10	6	1 : 2 : 5	Nat.	.70	1.25	1.10	3.30	1½	2	8	1.50
7	Chattanooga, Tenn.	2.68	5	6	1 : 2 : 5	"	......	......	......	......	....	2½	....	......
8	Cincinnati, O.	2.05	5	6	1 : 2 : 6	"	.60	.75	1.35	2.60	½	2	10	1.50
9	Cleveland, O.	2.17	10	6	1 : 2 : 4	"	......	......	......	......	1	2	....	......
10	Columbus, O.	2.20	10	6	1 : 2 : 4	"	.80	1.00	1.10	3.00	1	2	10	1.50
11	Denver, Colo.	2.13	5	6	1 : 2 : 4	"	1.25	.50	2.00	4.50	1	2	8	1.60
12	Des Moines, Ia.	1.96	7	4½	1 : 2 : 4	"	......	.40	1.25	......	1	1½	10	1.75
13	Erie, Pa.	2.30	10	6	1 : 2 : 5	"	......	......	......	......	1½	1½	....	......
14	Fort Wayne, Ind.	2.40	10	6	1 : 2 : 5	"	......	.65	1.15	......	1½	2	10	1.50
15	Grand Rapids, Mich.	1.59	10	6	1 : 2 : 5	"	.70	.40	1.00	......	1	2	10	1.50

16	Kansas City, Mo.	2 12	10	5	1 : 2 : 5	Nat.	......	80	1.00	......	1½	1½	8	1.40
17	Lafayette, Ind.	2.00	10	6	1 : 2 : 6	......	......	......	......	4.00	1	1½	10	1.50
18	Los Angeles, Calif.	1 80	No	6	1 : 3 : 6	Port.	2.50	.40	1.00	6 00	No	2	10	2.00
19	Milwaukee, Wis.	1.85*	5	6	1 : 2 : 5	Nat.	.55	.65	1.10	......	1	2	10	1.50
20	Minneapolis, Minn.	......	....	6	1 : 2 : 5	"	.80	.55	1.35	3.00	1	2	8	1.75
21	Montreal, Que.	3 25	10	6	1 : 3 : 4	Port.	2 84	.75	1.25	6.00	½	2½	10	1 25
22	Newark, N. J.	2.03	10	6	1 : 3 : 7 †	P. & N.	......	......	......	......	1½	2	....	......
23	New Orleans, La.	2.50	5	6	1 : 3 : 7	Port.	......	2.02	2.02	8.00	1½	2	10½	1.50
24	Newport News, Va.	2.63	10	6	1 : 2 : 5	Nat.	.95	.50	2.20	4 80	1½	1½	10	1 25
25	New York, N. Y.	2.56	10	6	1 : 3 : 6	Port.	2.50	.45	......	5 84	1	2	8	2 00
26	Omaha, Neb.	2.11	5	6	1 : 2 : 5	Nat.	.80	.70	1.40	5.00	1½	1½–2	10	1.75
27	Peoria, Ill.	1 96	5	6	1 : 1½ : 4	"	.55	1.00	1.50	4.50	1	1½	10	1.62
28	Philadelphia, Pa.	2 37	5–10	6	1 : 3 : 6	P. & N.	......	......	......	......	1	2	....	......
29	Pittsburg, Pa.	2.44	5	6	1 : 2 : 4	Nat.	.70	.65	1.70	......	1	2	9–10	1 55
30	Providence, R. I.	2.65	5	6	1 : 2 : 6	Port.	2.20	.63	2.00	5.10	1½	1½	10	1.62
31	Rochester, N. Y.	2.11	10	6	1 : 2 : 4	Nat.	70	1 00	1.10	4.00	1	2	8	1.50
32	San Antonio, Tex.	1.99	10	6	1 : 2 : 4	"	1.50	1.00	.75	4 40	No	2	8	1 50
33	San Francisco, Calif.	1.89	No	6	1 : 2½ : 7	Port.	2.88	.70	1.38	5.18	No	2½	9	2.00
34	Scranton, Pa.	2.20	10	6	1 : 3 : 7	"	1.90	1 00	1.25	4.20	1½	1½	10	1.50
35	Spokane, Wash.	2.29	10	4	1 : 3 : 6	"	4.50	.70	.98	7 65	1½	2	8	1.80
36	St. Paul, Minn.	2.55	10	6	1 : 2 : 4	Nat.	......	......	......	3.00	1	2	10	1.62
37	Syracuse, N. Y.	2 22	5	6–8	1 : 2 : 5 ‡	"	......	......	......	......	....	....	.	......
38	Toledo, O.	1.96	5	6	1 : 2 : 5	"	......	......	......	......	1	2	10	1 50
39	Toronto, Ont.	2.75	10	6	1 : 3 : 6	Port.	2.24	.79	1.60	5.70	¾	2½	9	1.62
40	Utica, N. Y.	2 35	10	5	1 : 2 : 5	Nat.	.85	.85	1 25	4.00	1	2	8	1.50
41	Washington, D. C.	1.79	5	6	1 : 2 : 5	"	.70	.40§	1 25§	3.50	1½	1½	8	1.20
42	Winnipeg, Man.	1.79	....	4½	1 : 3 : 6	Port.	3.75	1.00	1.10	5.74	1½	1½–2	9	1.65

* Including grading. † Also 1 : 3 : 5. ‡ Also 1 : 3 : 6. § Not including haul. ‖ Cushion course.

671. Table 47, page 442, shows the cost of maintenance of the asphalt pavements in Washington, D. C. These results are compiled from Table D, Asphalt Pavements on 6-inch Hydraulic Base, in the Report of the Operations of the Engineering Department of the District of Columbia for the year ending June 30, 1900. The

TABLE 45.

COST OF MAINTENANCE OF ASPHALT PAVEMENTS IN BUFFALO, N. Y., FROM 1885 TO 1897.*

Year Laid.	No. of Streets Paved.	Length of Guarantee.	Total Area of Pavement Maintained.	Cost of Repairs per Sq. Yd. per Annum.	Maintained After Expiration of Guarantee.	Area of Pavement on Streets Repaired.	Cost of Repairs per Year per Sq. Yd. of such Streets.
		Years.	Sq. Yd.	Cents.	Years.	Sq. Yd.	Cents.
1878	1	5	9 286	0.60	9	9 286	0.60
1879	1	5	7 264	4.15	13	7 264	4.15
1880	1	5	3 755	2.25	12	3 019	2.80
1881	1	5	8 876	2.00	11	8 876	2.00
1882	2	5	25 501	2.19	10	25 501	2.19
1883	3	5	35 815	6.91	9	35 815	6.91
1884	8	8	79 774	5.02	5	79 744	5.02
1885	15	5	113 498	7.49	7	110 418	7.49
1886	28	5	236 001	7.90	6	203 371	9.16
1887	14	5	126 490	5.06	5	122 780	5.21
1888	14	5	201 668	3.91	4	201 668	3.91
1889	40	5	249 333	2.24	3	244 084	2.29
1890	51	5	370 125	2.16	2	341 875	2.34
1891	43	5	419 579	1.02	1	323 743	1.32

* Compiled from an article on Repairs of Asphalt Pavements in Buffalo, N. Y., by Edward B. Guthrie, Chief Engineer, in Proc. Amer. Soc. of Municipal Improvements, Vol. 5, p. 123-29.

original table is arranged geographically by streets and gives the cost of repairs for each contract for each year after the expiration of the 5-year guarantee period. The results in Table 47 are the means of the annual cost of repairs for the several contracts, and take no account of the different areas covered by the different contracts; but the resulting error is not material. The most conspicuous feature of the table is that the pavements laid in 1878 cost much more for maintenance than those laid later, after the best method of doing the work was better understood.

Table 47 suggests comparisons with Table 45; but it is impossible to draw any reliable conclusions, since nothing is known con-

cerning the relative amount of traffic per unit of width, and also since nothing is known about the relative excellence of the state of repairs in the two cities. In each case there is a considerable variation in the results from year to year, depending upon the number of streets that were re-surfaced that particular year.

TABLE 46.

COST OF MAINTENANCE OF ASPHALT PAVEMENTS IN BUFFALO, N. Y., PER SQUARE YARD PER ANNUM FROM 1885 TO 1897.*

Years After Expiration of Guarantee.	Business Streets.				Residence Streets.			
	With Car Tracks.		Without Car Tracks.		With Car Tracks.		Without Car Tracks.	
	No. of Streets.	Cost per Sq. Yd.	No. of Streets.	Cost per Sq. Yd.	No. of Streets.	Cost per Sq. Yd.	No. of Streets.	Cost per Sq. Yd.
		Cents.		Cents.		Cents.		Cents.
1	20	5.1	12	3.2	6	4.0	34	1.3
2	21	11.8	16	12.4	8	5.5	57	2.9
3	15	11.4	12	6.7	8	4.3	50	4.5
4	11	15.7	9	11.7	7	4.8	43	7.5
5	8	16.7	7	13.8	9	11.9	39	6.2
6	6	17.2	5	13.1	5	6.3	26	4.9
7	1	23.9	2	18.0	3	6.6	13	7.2
8	......	......	......	......	1	1.2	6	4.7
9	......	......	......	......	......	......	6	2.9
10	......	......	......	......	1	2.5	4	2.7
11	......	......	......	......	1	4.7	2	3.4
12	......	......	......	......	1	4.3	1	3.7
13	......	......	......	......	......	......	1	10.6
Average..	....	14.8	....	11.2	....	4.7	....	4.8

672. In New York city, the average difference in contract price for a 15-year and for a 5-year maintenance for the three years preceding 1894 was $0.608, or 6.08 cents per square yard per annum, and for the three years following 1894 was 5.82 cents per square yard per annum. The area of pavements included was quite large, and hence the result is fairly representative.†

673. In Berlin, Germany, the contract price for the maintenance of the great majority of the asphalt pavements is 0.75 marks

* Repairs of Asphalt Pavements in Buffalo, N. Y., by Edward B. Guthrie, Chief Engineer, in Proc. Amer. Soc. of Municipal Improvements, Vol. 5, p. 123–29.

† E. P. North, Consulting Engineer to the Commissioner of Public Works of the City of New York, in *Engineering Record*, Vol. 44, p. 418.

TABLE 47.

COST OF MAINTENANCE OF ASPHALT PAVEMENTS IN WASHINGTON, D. C.

The results are in cents per square yard per annum.

Year Laid.	Area, Sq. Yd.	No. of Contracts.	Age of the Pavement, in Years.																	Average.
			6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	
1878	18 547	6	0.13	2.48	21.29	6.76	7.61	10.45	63.15	28.76	55.55	1.06	4.26	2.9	3.3	1.03	1.86	2.21	6.4	13.19
1879	99 262	15	0.05	0.05	1.70	2.01	5.24	8.91	10.61	11.95	3.08	8.85	4.04	2.54	1.4	3.49	3.72	7.01	.....	4.67
1880	74 609	12	0.15	.00	3.43	0.63	2.17	1.57	2.42	1.57	2.65	0.77	1.38	2.09	2.02	6.96	6.48	.....	.....	2.29
1881	95 995	22	1.1	1.36	1.55	1.35	2.7	4.67	1.4	3.20	1.79	3.84	2.88	4.63	16.89	1.97	.....	.....	.....	3.52
1882	82 489	11	0.62	0.76	2.17	2.93	16.18	2.28	7.12	3.53	3.47	3.12	6.29	2.24	2.57	.....	.....	.....	.....	4.02
1883	121 805	26	0.51	1.75	8.75	7.38	4.17	11.32	2.67	11.99	3.42	6.76	4.64	4.39	.....	.....	.....	.....	.....	5.61
1884	60 044	14	0.35	1.33	4.73	6.98	4.94	2.29	8.46	4.73	5.29	1.93	4.42	.....	.....	.....	.....	.....	.....	4.13
1885	32 516	11	.27	1.58	1.90	2.79	4.72	1.60	4.06	3.02	2.0	15.06	.....	.....	.....	.....	.....	.....	.....	3.70
1886	6 041	2	0	0	.80	.30	4.40	4.30	0.40	2.75	1.10	.....	.....	.....	.....	.....	.....	.....	.....	1.56
1887	8 529	1	.05	0.7	1.0	0.8	0.8	1.0	0.2	1.0	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.75
1888	None laid																			
1889	9 908	5	0	0.12	0	0.92	2.34	6.06	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	1.57
1890	89 930	8	.1[illegible]	.23	.12	.18	3.15	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.64
1891	87 397	22	.03	0	1.95	.22	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.55
1892	38 220	12	0	.02	.22	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.08
1893	42 198	14	0	0	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0
1894	36 193	11	0	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0
	Average	12	0.15	0.64	3.54	2.56	4.87	4.49	10.29	7.25	8.71	5.17	3.99	3.13	5.24	3.36	4.02	4.61	6.4	

per square meter (about 15 cents per square yard), provided the total amount of repairs in one year is not more than 5,000 square meters (6,000 sq. yd.); if the total repairs amount to more than 5,000 square meters in a year, the price is 0.50 marks a square meter (about 10 cents per square yard).

It is often stated that the cost of maintaining asphalt pavements in Europe is from 10 to 25 cents per square yard per annum, an amount which is considerably higher than the average for America; but all such data are indefinite and unreliable, since nothing is stated concerning the traffic and the state of maintenance. As a rule, the streets of Europe are narrower and the traffic per foot of width is heavier than in America; and therefore it is probable that the cost of maintenance in Europe is higher than in this country.

674. Prices of Repairs. Table 48 shows the prices paid for sundry repairs to asphalt pavements in Buffalo, N. Y., for a number of years.

TABLE 48.

CONTRACT PRICES FOR REPAIR OF ASPHALT PAVEMENTS IN BUFFALO, N. Y.*

Ref. No.	Items.	During the Year.				
		1896.	1897.	1898.	1899.	1900.
1	Average for new pavement, per sq. yd.	$2.97†	$2.55†	$2.17†	$2.60‡	$2.20§
2	Replacing concrete, binder, and topping, per sq. yd.	2.25	2.39	1.90	2.39	2.43
3	New asphalt surface, per sq. yd.	1.35	1.46	1.05	1.46	1.53
4	Skimming, per sq. yd.	.88	.98	.64	.98	1.01
5	Filling cracks, per lin. ft.	.02	.02	.01	.02	.02
6	Painting gutters, 1 ft. wide, per lin. ft.	.035	.04	.02	.04	.04
7	Replacing stone toothing, per lin. ft.	.17	.19	.15	.19	.19

* Annual Report of Board of Public Works for 1900, p. 69, and private correspondence.

† Including excavation, curb, drain tile, and a 5-year guarantee.

‡ Including excavation, curb, drain tile, and a 10-year guarantee.

§ Including only concrete, binder, topping, and a 10-year guarantee.

In Washington, D. C., the cost of small and irregular patches is based upon the volume of binder and of mixture for the wearing

coat used in making the repairs. The prices in the contract for repairs for the three years beginning July 1, 1900, are as follows: *

"1. Laying standard asphalt pavement ($2\frac{1}{2}$ inches of asphalt and 2 inches of binder—before compression) on a 6-inch hydraulic concrete base (1 N. C.: 2 S.: 5 S.)	\$1.77 † per sq. yd.
2. Laying standard asphalt surface ($2\frac{1}{2}$ inches before compression	0.91 " " "
3. Laying standard asphalt surface (2 inches before compression)	0.80 " " "
4. Laying standard asphalt surface (measured in cart)	0.60 per cu. ft.
5. Laying asphalt binder (measured in cart)	0.31 " " "
6. Laying standard asphalt surface by the burner method ‡ (measured in cart) . . .	1.00 " " "

No price is stated for painting the gutters, since the standard for new work requires brick gutters 2 feet wide, and the repairs to old asphalt gutters is made the same as in the remainder of the roadway. The placing of stone toothing along street-car tracks is done by the railroad company."

675. Cross Section of Asphalt Pavement. Fig. 119 and

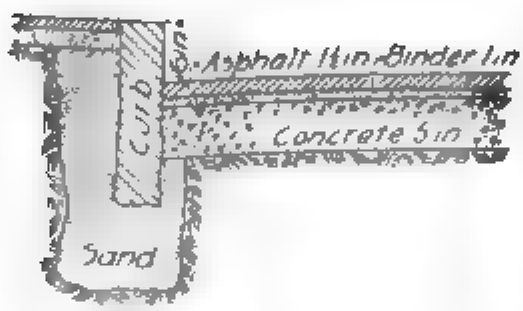

Fig. 119.—Sheet Asphalt Pavement.

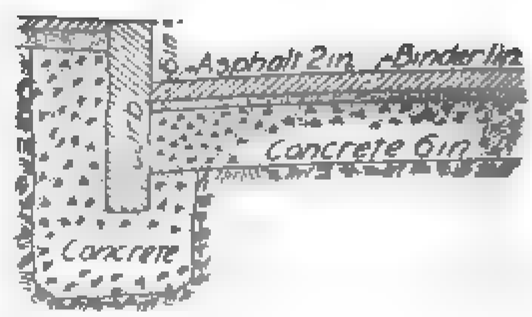

Fig. 120.—Sheet Asphalt Pavement.

120 show the typical cross section of an asphalt pavement. Asphalt is frequently laid upon an old cobble-stone pavement, or

* By courtesy of Maj. John Biddle, U. S. A., Engineer Commissioner of D. C.

† The contract price for entirely new work is \$1.72.

‡ Skimming—see § 660.

upon one of stone block or brick, and occasionally upon a macadam pavement.

676. Maximum Grades for Asphalt Pavements. Until within a few years, it has been assumed that the maximum permissible grade for a sheet asphalt pavement was 2 or 2½ per cent; but experience has shown that this limit is too low. It is now generally conceded that sheet asphalt may be laid on grades of 5 or 6 per cent, particularly in residence streets—where a clean, smooth, noiseless pavement is specially desirable, and where there is usually no great amount of traffic. With a 5 or 6 per cent grade, there may be a few days each year when the pavement is icy and too slippery for either comfortable or safe use. In New York city, on a street having a 6 per cent grade paved with asphalt on the sides and granite in the center, the traffic as a rule seeks the asphalt rather than take the granite, and in the same city traffic has deserted one street having a 5 per cent grade paved with granite for another having a 6 per cent grade paved with asphalt. A number of cities have sheet asphalt pavements upon a 7 per cent grade, as, for example, Peoria, Ill., Grand Rapids, Mich., Syracuse, N. Y., Troy, N. Y.; and Omaha, Neb., and St. Joseph, Mo., have asphalt pavements on an 8 per cent grade. Scranton, Pa., has a short piece of asphalt on a 13 per cent grade, San Francisco, Cal., a piece on a 16 per cent grade, and Pittsburg, Pa., one on a 17 per cent grade.

677. Merits and Defects of Sheet Asphalt Pavements. The advantages possessed by monolithic asphalt pavements constructed as described above are: (1) they produce neither dust nor mud; (2) they are comparatively noiseless, except for the clicking of the horses' shoes; (3) they do not absorb or retain noxious liquids, but facilitate their prompt discharge into the gutters and storm-water sewers; (4) they reduce the force of traction to a moderate amount (see Table 8, page 29); and (5) they afford a reasonably good foot-hold for horses.*

The defects of sheet asphalt pavements are: 1. The first cost

*For a discussion of the limiting grades of sheet asphalt pavements, see the preceding paragraph.

is comparatively great; 2, the cost of maintenance is large; and 3, such pavements are generally considered too smooth for steep grades (§ 676).

678. For a discussion of the relative merits of the different pavements, see Chapter XVIII.

Art. 3. Rock Asphalt Pavements.

679. This form of pavement is made by crushing bituminous limestone or sandstone, and laying it while hot upon a concrete foundation. In Europe this is the common form; and when the term asphalt pavement is used there, this kind is intended.

Rock asphalt pavements have been laid only to a comparatively small extent in America, it being claimed that there are only about 75,000 square yards now in use in the United States outside of California. Rock asphalt pavements have been used in a small way in California for many years, and San Francisco, Los Angeles, and other cities now have several miles of such pavements. Apparently both asphaltic limestones and sandstones are used in California; but the most of the so-called rock asphalts used for paving purposes are asphaltic limestones.

A bituminous limestone to be suitable for paving purposes should be as coarse-grained as possible, should contain between 9 and 10 per cent of bitumen soluble in carbon bisulphide, and should contain very little matter volatile below 400° F. Often one or more natural rocks are mixed to secure the proper proportion of bitumen; and sometimes a natural asphalt is added to the natural rock to increase the proportion of bitumen.

680. Construction. The asphaltic rock is quarried, and then crushed to about egg size by toothed rollers. These pieces are first reduced to powder and then sifted to uniform fineness. The powder is dropped through a hopper into a revolving cylinder like a coffee roaster, which is about 6½ feet in diameter, and is surrounded by a chamber the air in which is heated by a movable furnace placed just below it. The cylinder itself revolves and, since it is provided with blades arranged in screw form, the powdered rock is well mixed with hot air and is thus thoroughly heated to a temperature between 300° and 350° F. Specifications frequently permit the rock asphalt to be heated to but 200° to 250° F.

When the powder is hot enough, the furnace is removed from under the heater and a cart replaces it, into which the asphalt powder is discharged and hauled upon the work. The powder will retain its heat for several hours and so admits of being carted long distances without losing its heat, thus doing away with the necessity of having roasters at the point where the surface is to be laid, as was at one time the practice. For the best results, the mixture should be delivered upon the street at a temperature of not less than 250° F., although specifications sometimes permit a temperature of but 190° F.

The heated powder is spread upon the concrete base to a uniform thickness about 40 per cent greater than that required for the finished pavement. This must be done with great care in order that the material, which while hot has a great tendency to consolidate, may not be denser in one spot than another. The material is compacted by rolling and ramming in much the same way as is described for the artificial asphaltic paving compound (see § 629), except that as a rule the natural rock asphalt is not consolidated to so great an extent as is customary in laying the artificial mixture. The evidence of this is that a rock asphalt pavement will continue to shrink in thickness under traffic for a year or two, while the artificial mixture shrinks but little, if any, after completion.

681. The general appearance of the completed pavement is much the same as that of the pavement made of the artificial mixture, except that the European rock pavements are lighter in color. The claim is that European natural rock asphalt pavements are less slippery and less susceptible to changes in temperature than are American artificial asphalt pavements.

Not infrequently the term rock asphalt pavement is inappropriately applied to a pavement made of an artificial mixture of sand and of asphalt extracted from a natural rock.

ART. 4. ASPHALT BLOCK PAVEMENT.

682. There are two general forms of asphalt pavements, the sheet or monolithic and the block. The first has been fully described in the two preceding sections. The latter is constructed by first molding rectangular blocks composed of asphaltic cement

and crushed stone, and then placing these blocks side by side upon a gravel or concrete foundation. Asphalt paving blocks were first made in San Francisco in 1869; and at present there are in this country about 1,500,000 square yards of asphalt block pavement or about one twentieth as much as sheet asphalt. This form of pavement has been more largely used in Washington, D. C., than any other place; but comparatively large areas have been laid in Baltimore and in New York city.

683. The Blocks. At first crushed limestone was used, but now the blocks are made with crushed trap, granite, or gneiss. The asphaltic cement is mixed substantially as for sheet pavements. The proportions employed in making the blocks vary slightly with the climate and considerably with the fineness of the crushed stone, but are about as follows:

Asphaltic Cement	8 to 12 per cent
Limestone Dust	8 to 10 per cent
Crushed Stone	84 to 78 per cent.

Since the blocks contain larger fragments than sheet pavements, they contain a smaller per cent of voids, and hence can be made with a slightly smaller per cent of asphaltic cement.

The ingredients are mixed and heated about as for sheet pavements, and are then moulded while hot under heavy pressure. Formerly the blocks were made 5″ × 12″ × 4″ deep; but now they are made 4″ × 12″ × 3″ deep, and also 5″ × 12″ × 3″ deep. Tiles are made 8″ × 8″ × 2¼″ deep, and also with a hexagonal top surface having the same area as the square tile. The blocks are used for carriage ways, and the tiles for foot ways. The weight of the compressed blocks is about 165 pounds per cubic foot. After being compressed the blocks are cooled by being placed in water and then they are ready for laying.

Fig. 121 shows a perspective view and a cross section of a carriage way and a foot way paved with asphalt blocks.

684. Cost of Blocks. The cost of asphalt blocks varies in different cities, being in 1902 in Toledo, O., $115.00 per 1,000 for blocks 4″ × 12″ on top and 4″ deep, or about $1.70 per square yard; and in New York city, $33.00 per 1,000 for blocks 5″ × 12″ on the top

face and 3″ deep, or about $1.10 per square yard. The cost of the labor to lay varies from 8 to 10 cents per square yard.

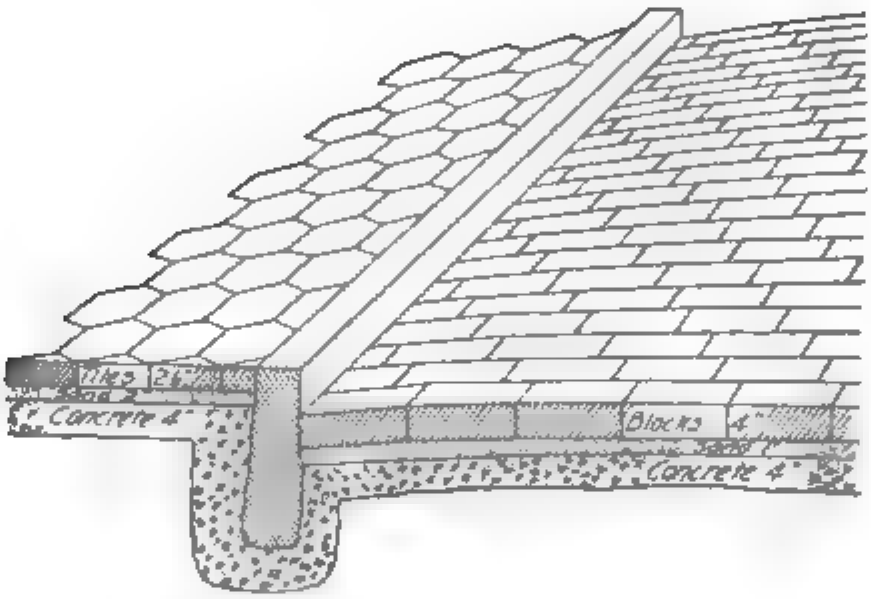

FIG. 121.—ASPHALT BLOCK PAVEMENT.

685. SPECIFICATIONS FOR LAYING. Below are the specifications employed for asphalt block pavements on carriage ways, in the City of Washington.*

686. Road-bed. The space over which the pavement is to be laid having been excavated to the proper depth below the surface of the pavement when completed, any objectionable or unsuitable matter below the bed will be wholly removed, and the space filled with good gravel or sand compactly rolled or rammed. The bed will be trimmed so as to be parallel to the surface of the pavement when completed, and the entire road-bed will then be thoroughly compacted by rolling with a roller weighing at least ten tons, or by thorough ramming at places which can not be reached by the roller. No extra allowance will be made for trimming and rolling.

687. Foundation. Two forms of foundation are used—concrete and gravel. The specifications are as follows, those for the concrete being abridged.

688. *Concrete Base.* This will be four inches thick when compacted, and will be made of broken stone and gravel, sand, and natural cement in such proportions that the quantity of gravel will be equal to the volume of voids in the broken stone; and the sand and the cement, mixed in the pro-

* Printed specifications received from Maj. John Biddle, U. S. A., Engineer Commissioner, January, 1902.

portion of one part cement and two parts sand, will be 20 per cent in excess of the volume of the voids in the combined gravel and broken stone. Upon the concrete will be laid a course of fine sharp sand, half an inch thick, to serve as a bed for the blocks. Special care will be observed to make the surface of the sand exactly parallel to the surface of the pavement when completed.

689. *Gravel Base.* Upon the road-bed prepared as above is to be laid a course of bank gravel, screened from all pebbles measuring more than one and one half inches in their largest dimension, of such a depth as to give five inches in thickness when compacted by rolling and ramming. Upon the gravel will be spread a layer of fine sharp sand two inches in thickness, to serve as a bed for the blocks. Special care will be observed to make the surface of the sand exactly parallel to the surface of the pavement when completed.

690. **Placing the Blocks.** The blocks will be 4×12 inches on top and five inches deep,* and a variation of one quarter of an inch from these dimensions will be sufficient grounds for rejecting any block. The blocks must be square and have sharp corners, and blocks having chipped or rounded edges will be rejected.

The blocks will be laid by pavers standing or kneeling upon the blocks already laid, and not upon the bed of sand. Each course will be formed of blocks of a uniform width and depth. The blocks will be laid with their length at right angles to the axis of the street; and shall be so laid that all longitudinal joints shall be broken by a lap of at least four inches. Each course of blocks will be driven against the course preceding it by a heavy wooden maul, in order to make the lateral joints as tight as possible. The longitudinal joints will be closed by pressing on a lever inserted at the end of the course adjoining the curb, and keying with a block cut to the required size.

When laid, the blocks will be immediately covered with clean, fine sand entirely free from loam or earthy matter, perfectly dry, and screened through a screen having 20 meshes to the inch. The blocks will then be rammed by placing an iron plate, 24 inches by 8 inches, and ⅝ inch thick, over four blocks, and striking on the plate with a rammer weighing not less than 45 lb. The ramming will be continued until the blocks reach a firm, unyielding bed and present a uniform surface, with the required grade and crown. Any lack of uniformity of the surface must be corrected by taking up the blocks, increasing or decreasing the sand bedding, and relaying them. When the ramming is completed, a sufficient amount of fine, dry sand, as above described, will be spread over the surface and swept into the joints.

The contractor will be permitted, if he so desires, to use the District steam roller No. 1 on this work. The men and material for its use are to be supplied by the District, and are to be paid for by the contractor during such use.

* In paving alleys it is usual to place the 5×12-inch face up.

691. It is better to lay asphalt blocks in hot rather than in cool weather. If the weather is cool, the blocks are firm and do not fit closely together; and consequently the edges chip or flow into the joint, thus making the upper surface of the block rounded and the pavement rough and comparatively noisy.

692. **Merits and Defects.** The advantages claimed for a pavement of asphalt blocks over a continuous asphalt sheet are: 1. It is less slippery, owing partly to the joints, partly to the roughening of the surface due to the use of a hard crushed stone, and partly to the fact that it does not retain moisture during sudden changes in temperature. 2. It can be laid on a steeper grade. 3. It can be laid in cities where there is no asphalt plant. 4. It can be taken up and relaid by common labor. 5. It can be repaired without special appliances or skilled labor. 6. Having numerous joints, it is free from irregular and unsightly contraction cracks. 7. It needs less repair than sheet asphalt.

The alleged disadvantages of an asphalt block pavement in comparison with a continuous asphalt sheet are: 1. Its first cost is more, since the wearing coat of the block pavement is 4 inches thick while that of the continuous sheet is at most only 2½ inches. 2. The edges of the blocks chip off, and the pavement wears rough. 3. It is slightly more noisy. 4. Owing to its numerous joints, it is less sanitary. 5. It is more expensive to clean. 6. Unless bedded with unusual care, the blocks have a tendency to crack. 7. It is less durable, particularly under heavy traffic.

693. **Cost.** The cost of the blocks is usually about $45.00 per 1,000 or about $1.70 a square yard. The cost of laying, sanding, etc., is about 8 cents a square yard with common labor at $1.50 for 10 hours. The total cost of an asphalt block pavement on a foundation of 6 inches of gravel or broken stone, including the preparation of the subgrade and the hauling of the blocks, in different cities varies with freight charges from the factory, but is usually from $1.75 to $2.25. In Washington, where there is a block factory, the price from 1897 to 1900 was uniformly $1.77 per square yard on gravel, exclusive of grading. In 1901 in Washington, the price on a 6-inch hydraulic concrete base was $2.00 per square yard.

694. **Durability.** Apparently there are no statistics as to the cost of maintenance of asphalt block pavements. Formerly

the blocks were made of crushed limestone, and wore fast and very unevenly; but since 1893 the blocks have been made with harder stone and have given better satisfaction.

ART. 5. ASPHALT MACADAM.

695. Very recently it has been proposed to use asphalt as a binding material for crushed stone, the resulting product usually being called asphalt macadam, but sometimes, and less appropriately, bituminous macadam. Doubtless this use of asphalt has been suggested by a former and similar use of coal tar (see § 709). Asphalt concrete would not be an inappropriate name. There are two slightly different methods of applying the asphalt, both of which have been patented. They will be referred to as Warren's and Whinery's, after the inventors.

696. WARREN'S METHOD.* Upon the subsoil is placed a 4-inch layer of broken stone which is thoroughly rolled. On this stone foundation is spread a coat of thin asphaltic cement, which enters the interstices of the stone holding its fragments together and forming a surface with which the wearing coat will readily and firmly unite. The asphalt macadam consists of a mixture of asphaltic cement and broken stone, the fragments of the latter varying from 1 to 2 inches in the largest dimensions to fine dust. The ingredients of the asphaltic macadam are mixed about as described for the wearing coat of the ordinary asphalt pavement (§ 627). The mixture of asphaltic cement and stone is spread, while still hot, of such a thickness as to be 2 inches after being thoroughly rolled with a road roller (§ 336) weighing 15 to 20 tons. On top of the asphalt macadam is spread a layer of asphaltic cement, partly to seal the surface against the entrance of air and water, and partly to bind together the fragments forming the wearing surface. While the surface of the asphaltic cement is still sticky there is spread over it a thick coat of fine stone chips, which are then rolled and the road is ready for traffic.

The finished roadway presents a rough gritty surface, which has more of the characteristics of an ordinary broken-stone road

* Jour. Assoc. of Engineering Societies, Vol. 28, p. 297–302; *Engineering News*, Vol. 47, p. 79–80; *Engineering Record*, Vol. 45, p. 84–85.

than of the usual asphalt pavement. Less asphaltic cement is required for a given thickness of asphalt concrete than for the asphalt mortar of the wearing coat of the ordinary asphalt pavement, since the larger the fragments of the aggregate the less the per cent of voids, and consequently the less cement required. It is claimed that no single stone has been dislodged in any of the seven cities in which experimental sections have been built. It is also claimed that asphalt macadam is superior to ordinary asphalt pavement, since the angular fragments of the broken stone used in the former are less mobile than the rounded sand grains used in the latter, and hence the cement in the former may be made softer and may also be worked at a lower temperature than in the latter. The softer the asphaltic cement, the more durable it is; and the lower the temperature at which it is worked, the less the danger of damage by overheating it.

697. WHINERY'S METHOD.* The foundation may be either broken stone or hydraulic cement concrete, depending upon the relative cost of the two and also upon the supporting power of the subsoil. The wearing coat consists of a layer of crushed stone the voids of which are filled with a mixture similar to that used for the wearing coat of sheet asphalt pavements. Broken stone of properly graded sizes is spread on the foundation to the requisite thickness, which, either before or after it is thus spread, is heated to a temperature of about 300° F. A hot mixture of asphaltic cement and mineral grains is spread over the top of the layer of hot crushed stone in a sufficient quantity to fill the voids in the stone and to level up the unevenness of the surface, the layer being properly graded with paving rakes. When this operation is completed a steam roller of the asphalt type weighing not less than ten tons is to be operated over the surface until (1) the plastic composition is forced into the voids in the crushed stone, (2) the unevenness of the surface is filled up, and (3) the whole mass is thoroughly compressed and solidified. The roadway is then complete, and after giving it time to become cold and hard the street is opened to travel.

No pavement of this kind has been constructed, but the inventor, an engineer of large experience in laying asphalt pavements,

* *Engineering News*, Vol. 45, p. 413–14.

claims that it will have the following advantages over ordinary sheet asphalt pavements. 1. The first cost will be materially less. 2. It will offer a better foothold to horses. 3. It will be at least as durable as the ordinary sheet pavement. 4. It will not shift under travel and work into waves. 5. It will not crack. 6. It can be repaired more cheaply and with less skilled labor than can the ordinary sheet pavement. On the other hand the asphalt macadam will not be so smooth and probably not so noiseless as the ordinary asphalt pavement.

ART. 6. COAL-TAR ROADS AND PAVEMENTS.

698. Asphalt is a natural bitumen, while coal tar is an artificial bitumen. The latter is produced by the distillation of coal, and is usually a bi-product in the manufacture of illuminating gas. Tar is a very complex hydro-carbon, and its character varies considerably with the system of manufacture. It naturally contains volatile oils and water; and when re-distilled produces what is known to the trade as paving pitch or paving cement, which is designated as distillate No. 1, 2, 3, 4, 5, or 6, according to its hardness. Distillate No. 4, which is much used as a substitute for asphalt, has a specific gravity of about 1.30, and contains about 65 to 70 per cent of bitumen soluble in carbon bisulphide. It will almost stick to the fingers when worked in the hands at a temperature of 70° F. It is very susceptible to changes of temperature, becomes semi-fluid under the heat of summer, and hard and brittle at ordinary winter temperatures. It must be shipped in tight barrels. No. 6 is much used for filling the joints of brick pavements, is considerably harder than No. 4, and may be shipped in slack barrels. The price of tar varies from 6 to 10 cents a gallon according to the locality and the demand.

Coal tar was formerly employed to a considerable extent for paving purposes, the resulting pavement being much the same as sheet asphalt; but this use of coal tar has now practically been abandoned. Tar is still used to a limited extent, chiefly in Canada and England, as a binding material for macadam for carriage ways; and is also used a little in the construction of foot ways.

699. COAL-TAR PAVEMENTS. Numerous attempts have been made to construct a pavement by the use of coal tar as a cementing

material in place of asphalt or in conjunction with it. This form of pavement was laid somewhat extensively in Washington, D. C., from 1872 to 1887. The earlier pavements were laid under many different patents, of many different mixtures, receiving their name generally from that of the patentee. Most of them were signal failures, although some were fairly durable. In 1886 Congress in making an appropriation for pavements in Washington stipulated that no contract for an asphalt pavement should be made at a higher price than $2.00 a square yard; and no bids having been received for asphalt pavements for less than $2.25, a considerable quantity of coal-tar pavements were laid during the years 1886 and 1887.

700. Specifications. The specifications employed at Washington, D. C., in 1886–87 for coal-tar distillate pavements are as follows:*

701. "*Road-bed.* The space over which the pavement is to be laid shall be excavated to the depth of six inches below the top of the surface of the pavement when completed. Any objectionable or unsuitable material below the bed shall be removed and the space be filled with clean gravel or sand well rammed. The bed shall then be trimmed so as to be exactly parallel to the surface of the new pavement when completed, and the entire road-bed shall be thoroughly rolled with a heavy steam-roller.

702. "*Base.* The base shall be composed of clean broken stone which will pass through a three-inch ring and which shall be thoroughly coated with No. 4½ coal-tar paving cement in the proportion of about one gallon to the square yard of the base. This layer shall be well rammed and shall then be rolled with a steam-roller. The depth after rolling shall be 4 inches.

703. "*Binder.* The second or binder course shall be composed of clean broken stone, thoroughly screened, not exceeding 1½ inches in the largest dimension, and No. 4 coal-tar paving cement. The stone shall be heated to a temperature between 230° and 250° F. by passing it through revolving heaters, and shall be thoroughly mixed by machinery with the paving cement in about the proportion of one gallon of tar to one cubic foot of stone. The mixture shall be hauled upon the work, be spread upon the base course at least 2 inches thick, and be immediately rammed and rolled with hand and steam-rollers. The base and the binder shall together measure at least 4½ inches when compacted.

704. "*Wearing Surface.* The wearing surface shall be composed of the following materials, in the following proportions:

* Report of the Operations of the Engineering Department of the District of Columbia for the year ending June 30, 1890, p. 165–66.

Clean sharp sand	63 to 58 per cent
Powdered limestone	28 " 23 " "
Paving cement	13 " 15 " "
Hydraulic cement	0.90 " "
Slaked lime	0.15 " "
Flower of sulphur	0.10 " "

"The sand shall be clean sharp river sand, free from clay, and of such a size that not more than twenty per cent shall be retained upon a sieve of twenty meshes to the inch, and not more than five per cent shall pass a sieve of seventy meshes to the inch, about sixty per cent to be coarser than forty meshes to the inch. The powdered stone or stone dust shall be the residue from crushing the stone for the base and the binder; and shall be of such a degree of fineness that 16 per cent by weight shall be an impalpable powder, and that the whole of it shall pass a No. 26 screen. The paving cement shall be composed of refined Trinidad asphalt, 25 to 30 parts, and No. 4 coal-tar paving cement, 75 to 70 parts. The refined asphalt shall contain at least sixty per cent of bituminous matter soluble in carbon bisulphide. The No. 4 coal-tar paving cement shall correspond to a standard to be furnished by the Engineer Commissioner, and shall be free from excess of sooty matter, napthaline, and creosote oils. The hydraulic cement, lime, and sulphur shall be of the best commercial quantity. The materials for the wearing surface shall be heated to not over 260° F.,—the paving cement in kettles, the sand and stone dust in revolving heaters. The hydraulic cement, lime, and sulphur shall be added cold to the sand and stone dust in the sand box before going to the mixer. The ingredients shall be thoroughly mixed by approved machinery.

705. "*Laying.* The wearing coat shall be hauled upon the street, and be spread upon the binder course in a layer 2 inches thick with hot iron rakes and other suitable appliances. It shall be immediately compacted, while hot and plastic, with hot tamping irons and hand rollers. It must be thoroughly rolled and cross rolled until it has become hard and solid. In spreading the material the joints between the different loads shall be diagonal to the line of the street. The surface shall be finished with a dusting of dry hydraulic cement rolled in. In cool weather, or when ordered, the carts carrying the mixture shall be protected with canvas covers. The wearing coat shall be at least 1½ inches thick after rolling."

706. COST. Construction. The first cost of coal-tar pavements has been only a trifle under the prevailing prices for sheet-asphalt pavements. In Washington D. C., from 1873 to 1878, 745,305 square yards of coal-tar pavements of various kinds were laid at prices ranging from $1.74 to $3.70 per square yard. These pavements proved very unreliable, either through inherent defects in the materials used or owing to faulty methods of construction;

and consequently for some years thereafter no coal-tar pavements were laid. A return to coal-tar pavements in 1887–89 was forced upon the city by the act of Congress which specified that no contract should be made for asphalt pavements for a greater price than $2.00 per square yard. The lowest bid received for such pavements was $2.25 per square yard, and consequently a considerable quantity of tar pavements was laid, the prices of it being from $1.98 to $2.00 per square yard. These pavements were laid under the specifications in § 700–05.

707. Maintenance. Up to June 30, 1887, the average cost of maintaining all the coal-tar distillate pavements laid from 1871 to 1878 was 7.2 cents per square yard per annum; but the work of one contractor was so poor that it was necessary to re-surface the pavements laid by him when they were only two years old, and excluding the work of this contractor the cost of maintenance was 5.5 cents per square yard per annum.* "For the first five years, the annual average was 3.7 cents per square yard; for the second five years, 6 cents; and for the last five years, 6.6 cents. That a durable coal-tar pavement can be laid is proved by the fact that the average cost of maintenance of 158,595 square yards of Vulcanite pavement (for specifications of the same see § 700–05) was only 2.9 cents per square yard per annum for fourteen years, for the first five years the average being 0.3 cents per square yard, for the second five years 4.2 cents per square yard, and for the last four years 4 cents per square yard." †

Up to June 30, 1901, the average cost of maintenance of the tar pavements laid in Washington in 1887–89 had been 3.5 cents per square yard per annum. This result was obtained as follows: The Report of the Operations of the Engineering Department of the District of Columbia for the year ending June 30, 1901, pages 8 to 51, gives the location, the kind, and the details of the cost of all the pavements in Washington, including the average annual cost per square yard for the pavement laid under each contract.‡ During 1887–89, 132,063 square yards of pavement were laid under

* Report of Engineer Commissioner, June 30, 1887, p. 60–62.

† *Ibid.*, p. 62.

‡ For the cost for each individual year, see the Reports for 1898, p. ix–xvii; 1899, p. 4–11; 1900, folding sheets between pages 82 and 83.

thirty-six contracts, and the average of the annual cost under the several contracts is 3.5 cents per square yard, as stated above. This method of deducing the average takes no account of the areas of the different pieces, and consequently is not mathematically correct; but the error is immaterial. The areas range mostly from 2,000 to 4,000 square yards, one, however, being 18,000. The average age of the pavements was 12.6 years. Of the thirty-six pieces of tar pavement as above, fourteen had been re-surfaced before July 1, 1901, the average age at the time of re-surfacing being 11.7 years.

708. The above data on the cost of maintenance of coal-tar distillate pavements suggest a comparison with the corresponding data for asphalt pavements. According to Table 47, page 442, there were laid in Washington during the years 1886, 1887, 1889, and 1890, 114,408 square yards of asphalt pavement, for which the cost of maintenance was 1.13 cents per square yard per annum. The corresponding cost of tar pavements laid from 1886 to 1889 was 3.5 cents, and therefore we may conclude that the cost of maintenance of tar pavements is practically three times as much as that of asphalt pavements. Any attempt thus to compare the cost of maintenance of tar and asphalt pavements is open to the criticism that the mathematical process of deducing the average is not strictly correct, and also that the amount of traffic may not be the same in the two cases, and further that part of the repairs in each case was due to openings made in the streets independent of the condition of the pavements; but nevertheless the general conclusion is at least approximately true. The use of tar pavements has practically been abandoned, chiefly on account of the excessive cost of maintenance.

709. TAR MACADAM. Broken stone with a tar binder has been used for road purposes in a comparatively small way in England for twenty or thirty years past; and the experience of Hamilton, Ontario, Canada, with this form of pavement has lately attracted considerable attention in this country. In a general way, two methods have been employed in using tar as a binder for broken stone, viz.: (1) the broken stone is mixed with sufficient tar more or less nearly to fill the voids, and then the mixture is deposited and compacted, the process being very much the same as that em-

ployed in laying hydraulic cement concrete; or (2) the broken stone is laid and rolled, and then a layer of tar is added and rolled, the intention being to force the tar into the interstices of the broken stone much as the stone-dust binder is worked into a broken-stone road. The product in the first case could appropriately be called tar concrete, and in the second tar macadam; and they will be so designated in this discussion. The former seems to be the more common in England, and the latter in Canada. Notice that these two methods are substantially the same as Warren's and Whinery's method for making asphalt macadam—see § 696 and § 697, respectively.

710. The Tar. The tar should contain not more than 5 per cent of water, and not less than 55 per cent of pitch. The ordinary gas tar should be boiled until it is capable, when cool, of being drawn out into thread-like filaments; and the best results are not likely to be obtained by attempting to secure the proper consistency by adding thicker tar, since it is difficult to get a uniform mixture. Any clean broken stone or gravel may be used.

711. The Construction. The subgrade is prepared as for a pavement or for the ordinary broken-stone road, and the foundation consists of a layer of broken stone, usually 4 inches thick, which is thoroughly rolled.

In making tar concrete, care must be taken thoroughly to mix the tar and the stone, the former being hot and the latter dry. The mixing is done with shovels on a board platform, the tar being poured over the stone. Each fragment of stone should be thoroughly covered with tar; but more tar than enough to fill the voids is objectionable, since it increases the cost and decreases the durability of the road. Usually 10 or 12 gallons are required for a cubic yard of unscreened stone. The mixture is then placed in the road, and rolled while hot with the usual road roller, sand or dust being sprinkled over the surface to prevent the tar from sticking to the roller. Only a comparatively small amount of rolling is required to consolidate the mass. Not infrequently a wearing coat, consisting of a half inch to 1 inch of tar and screenings, is added on the top of the tar concrete; and herein the two methods referred to above merge one into the other.

In laying tar macadam, the broken stone is rolled until the

fragments do not move under the foot in walking over the surface, and then a layer of hot tar is poured upon the surface and is evenly spread over it with brooms or shovels, after which it is rolled. If honeycombed spots appear while the rolling is in progress, more tar is added. After the surface of the layer of broken stone has been thoroughly filled with tar, the surface is flushed with moderately soft tar, and over this is strewn a thin layer of stone chips about $\frac{1}{8}$ to $\frac{1}{4}$ inch in longest dimension; and then the surface is again rolled, after which the road is thrown open to traffic.

712. Cost. In Hamilton, Ontario, the cost of tar-macadam roads is as follows: broken limestone 95 cents per cubic yard delivered; coal tar $2.60 per barrel on the road; labor 18 cents per hour; and the total cost of the tar-macadam roadway 85 cents per square yard.

713. Merits and Defects. Obviously tar concrete and tar macadam are suitable only for comparatively light-traffic roads, and are more appropriately compared with ordinary broken-stone roads than with asphalt pavements. The use of a tar binder renders the roadway impervious to water, makes it frost proof, lessens the tendency of the road materials to grind to powder, and consequently decreases the tendency to produce dust and mud. It is easily cleaned, since there is less likelihood of loosening the surface stones; and it is easily repaired where opened for water or gas connections.

It is hardly probable that tar macadam will come into anything like general use, either for country roads or for city streets. The cost of tar macadam is nearly or quite as much as that of the ordinary broken-stone road (compare § 712 with § 359–62); and the construction of the former is neither so simple nor so certain as the latter. Tar macadam is of doubtful durability, since coal tar is subject to oxidation by the atmosphere, which renders it brittle and devoid of cementing power. Tar is affected by changes of temperature, and becomes friable in cold weather and soft in warm. There is less chance of success with tar macadam in the future than in the past, since in the present stage of manufacture, water gas is being substituted largely for coal gas, the quantity of gas tar produced is diminishing, its price is increasing, and its quality is deteriorating.

It is probable that the most favorable field for tar macadam is as a substitute for ordinary crushed stone on grades so steep as to wash seriously, and as a substitute for cobble gutters on crushed-stone streets.

CHAPTER XIV.

BRICK PAVEMENTS.

715. A brick pavement consists of brick set on edge on a suitable foundation—either concrete, gravel, a course of brick flatwise, or a layer of plank. Such pavements have been used in Holland for perhaps a century, and to a much less extent and for a shorter period in northern England. Brick pavements were first used in the United States in 1870 at Charlestown, W. Va., a place having a population of 12,000. The experiment was tried with a short section—less than a block;—and in 1873 a block on the principal business street was laid with a good quality of building brick, and is still in service after 29 years. A block of brick pavement, laid in 1875 on a leading business street of Bloomington, Illinois, a place of 20,484 population in 1890, though constructed of an inferior building brick made of a superior clay, continued in service for 20 years.

At present brick is the only paving material employed in most of the smaller cities of the Mississippi Valley, and it is used extensively in many of the larger cities in that territory. In all parts of this country, the use of brick for residence streets and light traffic business streets is rapidly increasing. A recent canvass shows about as much brick pavement in progress as granite block, asphalt, and wood combined. There are in this country nearly two hundred plants devoted to the manufacture of paving brick, some having annual outputs of 60,000,000 to 100,000,000 bricks.

ART. 1. THE BRICK.

716. A paving brick is simply a brick which, owing to careful selection of the clay and to skilful manufacture, is so hard and tough that it will resist the crushing and the abrading action of the traffic.

717. THE CLAY. Three distinct classes of clay are employed in the manufacture of paving brick: surface clays, impure fire clays, and shales. Surface clays are almost exclusively used for the manufacture of building bricks; but are not ordinarily suitable for making paving bricks, since it is practically impossible to burn them hard enough without their losing their shape. On account of its infusibility, pure fire clay is unsuitable for making paving brick, the brick being expensive to burn and lacking density, hardness, and strength; but quite impure fire clay makes a fair quality of paving brick, although the process of manufacture is comparatively expensive. Bricks made from impure fire clay are usually light in color, varying from cream to buff, and ordinarily are quite porous, absorbing from 2.5 to 7.0 per cent of water. Most paving bricks are made from shale,—an impure, hard, laminated clay which has been subjected to great pressure by the superincumbent earth strata. Shale is the most widely distributed of the laminated rocks, and makes a much better and cheaper paving brick than either surface or fire clay.

The different classes of clay so shade by imperceptible degrees one into the other that it is impossible sharply to discriminate them. Surface clays are soft and unconsolidated, and are found at or near the natural surface. Shales are dense and rock-like, but are easily reduced to powder and are readily worked into a plastic mass when mixed with water. Shale is often incorrectly called soapstone, from which it differs in nearly every respect. Shale is also frequently, but erroneously, called slate, from which it differs only slightly in origin and composition; but slate, unlike shale, can not be rendered plastic by mixing it with water. The only method of distinguishing between shale and impure fire clay, except by a kiln test, is the fact that shale gives a conchoidal fracture while fire clay does not.

718. Chemical Composition. It is not wise to enter into any extended consideration of the chemical composition of brick clays, since the subject is very complicated, and since the engineer is interested only in the physical properties of the finished product and should not attempt to prescribe the materials or to limit the methods employed by the manufacturer. However, a brief discussion of the subject may be of value as showing some of the limi-

tations upon the manufacture. Clay varies widely in its chemical composition, the essential ingredient being kaolin, a hydrous silicate of alumina having the composition:

Silica	46.3	per cent
Alumina	39.8	" "
Water	13.9	" "
Total	100.0	" "

Kaolin may be considered pure clay, but is rarely if ever found pure in nature. It is commonly mixed with varying quantities of silica, lime, magnesia, ferric oxide, potash, and soda. The presence of these substances, which may be regarded as the impurities of clay, and the physical condition under which they exist, cause the wide variation in the clays themselves and to a great extent in the product made from them.

The chemical composition of shale suitable for making paving brick usually ranges between the limits given in Table 49.*

TABLE 49.

CHEMICAL COMPOSITION OF PAVING-BRICK SHALES.

CONSTITUENTS.	MIN.	MAX.	AVER.
Silica (SiO_2)	49.0 %	75.0 %	56.0 %
Alumina (Al_2O_3)	11.0 "	25.0 "	22.5 "
Ignition loss (mainly H_2O)	3.0 "	13.0 "	7.0 "
Moisture (H_2O)	0.5 "	3.0 "	1.5 "
Total non-fluxing constituents			87.0 "
Sesquioxide of iron (Fe_2O_3)	2.0 "	9.0 "	6.7 "
Lime (CaO)	0.2 "	3.5 "	1.2 "
Magnesia (MgO)	0.1 "	3.0 "	1.4 "
Alkalies (K_2O, Na_2O)	1.0 "	5.5 "	3.7 "
Total fluxing constituents			13.0 "
Grand total			100.0 "

Silica is practically infusible, and its presence prevents, or at least reduces, the tendency of the clay to crack, distort and shrink; but the more silica the greater plasticity and adhesiveness of the

* Vitrified Paving Brick, by H. A. Wheeler, p. 18. 84 p. 3½"×5". T. A. Randall & Co., Indianapolis, Ind., 1895.

clay, and the less the strength and the toughness of the brick. Alumina will resist the highest temperature, and gives plasticity and adhesiveness to the clay and strength to the brick; but it causes the clay to shrink, warp, and crack in drying. Iron in considerable quantities has a fluxing effect with silica, cementing it together and giving it strength. Iron is not the most valuable of constituents in this regard, and its presence is not essential to a first-class paving brick. The red color of brick is due to the presence of iron, but more to its form than to its amount. Many erroneously believe that only red brick have sufficient strength and durability for paving purposes. Lime and magnesia are infusible by themselves or with alumina, but fuse in the presence of an excess of silica and give strength to the brick. If the lime is in the form of feldspar or a silicate, the more the better. But if it is present in the form of carbonate, it weakens the brick; and if present as concretions or pebbles, and not finely ground, the quicklime resulting from the burning is likely to cause swelling or cracking when the brick is wet. Potash (K_2O) and soda (Na_2O) fuse at lower temperatures than the other constituents of clay, and their presence in suitable quantities is very desirable.

719. Physical Properties. A chemical analysis of a clay may furnish sufficient evidence upon which to condemn it for brickmaking purposes, but never enough for its indorsement. The following physical properties are important factors in determining the value of a brick clay: 1, its plasticity; 2, the amount of water required to make a plastic mass; 3, the amount of shrinkage, both in burning and in drying; 4, the rapidity of drying and also of burning; 5, the temperature of incipient and complete vitrification; 6, the density before and after burning; and 7, the strength of the burned brick.

720. MANUFACTURE OF THE BRICK. Soft, homogeneous clay may be run through rollers, to crush the lumps, and from the crusher it may go directly to the brick machine; but it is usually desirable to run it first through a pug mill, where it is mixed and worked with water into a plastic mass. Hard clays and shales are usually reduced to a powder in a dry pan, which consists of two heavy rollers or wheels running in a revolving pan having a perforated bottom. It is important to have the clay finely pulverized, be-

cause it will then fuse at a lower temperature, and also because fineness is necessary to the production of an even and close-grained texture which conduces to make the brick tough and impervious. The powdered clay is screened and then tempered with water in the pug mill or a wet pan. Fire clays are sometimes both crushed and tempered in a wet pan, which is similar to a dry pan except that the bottom is water tight. The wet pan gives better results than the pug mill, as the clay can be retained in the pan until it is thoroughly tempered; but as it requires a large plant, and takes more labor and power, it is not usually used for paving brick. The more thoroughly the clay is worked or tempered, the more uniform and better will be the brick.

721. Molding. Paving brick are usually made by the stiff-mud process, although a few yards still use the old-fashioned soft-mud and re-pressing system. The molding is usually done by an auger machine which forces the tempered clay or stiff mud through a die, thus giving a continuous bar of compressed clay which passes under an automatic machine that cuts the bar into brick of the desired size. Instead of an auger producing a continuous stream of clay, reciprocating plungers are sometimes employed, which give an intermittent bar. The auger machine is the cheapest, and is almost universally used. Formerly the dies were made about $4\frac{1}{2} \times 2\frac{1}{2}$ inches in size, producing an end-cut brick; but of late dies $9 \times 4\frac{1}{2}$-inches are being used, a process which gives a side-cut brick. An active discussion is now going on as to the relative merits of the resulting brick; but apparently there is no material difference between the two. The weak point of the stiff-mud process is the laminations that must inevitably result from pushing a stream of clay through a fixed die. The friction of the sides of the die will cause differential speeds in the flow of the clay, and these variations must necessarily result in laminations in the clay bar. If the air has been expelled from the clay by the pug mill, these lines can be largely closed up again by a properly shaped die, and a first-class brick will result in which the laminations will be inconspicuous and of no importance; but if the air has not been expelled, or if the former and the die are not properly designed, there will be a number of concentric lines that divide the cross section of the brick into a series of shells or concentric

cylinders which greatly weakens the brick. These laminations vary with the character and the condition of the clay; and as a rule, the more plastic the clay the more prominent the laminations.

722. Re-pressing. After leaving the molding machine, stiff-mud brick are usually re-pressed. Re-pressing makes the brick more symmetrical in form and of better appearance, but can not increase its solidity or decrease the laminations; and it is not certain that re-pressing, by breaking the original bond of the clay, does not decrease the strength and durability of the brick. The effect of re-pressing upon the internal structure of the brick varies with the character of the clay, the machine used in molding, the method of molding, and the force used in re-pressing. Experiments * seem to show that re-pressing slightly improves end-cut die-molded brick, and slightly damages side-cut brick. Re-pressed brick are more uniform in shape, and therefore make a more even pavement; and for this reason they may perhaps wear longer. Re-pressing costs about 2 cents a square yard of pavement, and its economic value is not yet established.

After being molded, or after being re-pressed, the brick are placed on trucks or cars, and conveyed to the dry house. Thorough drying greatly facilitates the burning of the brick.

723. Burning. Paving brick are usually burned in down-draft brick-ovens having fire pockets or furnaces built in their outer walls. The bottoms of the kilns are perforated to allow the gases to pass through the flues, which are beneath the floor, and which lead to the chimney. The fire passes up from the furnaces into the kilns, then down through the brick to be burned to the flues, and thence to the chimney. The burning is the most critical step in the manufacture of paving brick. At first the heat is applied slowly in order to drive off the water, without cracking the brick, which contain from 20 to 30 per cent after being dried. A low heat is continued until the smoke passing off shows no further signs of steam or "water-smoke," after which the fires are gradually increased until the temperature throughout the kiln is sufficient to vitrify the brick. Most shales vitrify at from 1,500° to

* Prof. Edward Orton, Jr., p. 100–06 of Report of the Paving Brick Commission of the National Brick Manufacturers' Association. T. A. Randall & Co., Indianapolis, Ind., 1897.

2,000° F.; but impure fire-clays require from 1,800° to 2,300° F. From seven to ten days are required to raise the entire kiln to the vitrifying temperature.

There has been much discussion as to the meaning of the term vitrification as applied to brick making. Literally speaking, to vitrify means to render glassy; but as applied to clay working, vitrification has come to mean incipient fusion of the particles of the clay into a new chemical compound. The degree of vitrification increases with the temperature, and the logical end of the process is complete fusion. A clay is partially vitrified if its constituents have begun to unite by heat into a compound silicate, even though it may not have a glassy fracture. The physical peculiarities which mark vitrification in a burnt clay are the conchoidal fracture, the absence of pores, and the blending of the ingredients into one mass. Cracks, fissures, and cavities may be found, but porosity must not exist in a well vitrified brick, and the original particles must have begun to cohere by the bond of heat instead of the bond of plasticity. Within limits the degree of vitrification in a burned clay is measured by its ability to absorb water. A lightly burned brick will greedily asborb water, and the greater the degree of vitrification the less the water absorbed, a perfectly vitrified brick absorbing absolutely no water.

After the bricks have been vitrified entirely through, the kiln is tightly closed and allowed to cool very slowly. Rapid cooling renders the brick brittle; but by slow cooling they are annealed and rendered tough. Slow cooling is the secret of toughness, and the slower the cooling the tougher the brick. The annealing is frequently unduly hurried, much to the detriment of the toughness of the brick. The kiln is often cooled in three to five days, when seven to ten would materially improve the product and usually would be worth the extra cost.

With the utmost care a considerable per cent of the contents of the kiln are unsuitable for paving purposes, because of some being under-burned and some over-burned. With shale 70 to 80 per cent of first-class paving brick is a high average, while with impure fire clay 80 or 90 per cent may be produced.

724. Size of the Brick. Formerly there was considerable difference of opinion as to the best size for paving brick, some advocating

2″ × 4″ × 8″, others 3″ × 4″ × 9″, and a few 4″ × 5″× 12″. The first is known as a brick and the last two as paving blocks. It was often claimed that one or the other size made the better pavement, but there is no material difference in the quality of the pavement between the different sizes, except that possibly the block may be a little more durable.

725. The advantages of the building-brick size are: (1) being smaller they are more easily vitrified, and therefore a little cheaper to manufacture; and (2) brick unsuitable for use in the pavement can be more readily disposed of for building purposes, a fact which tends to cheapen the cost of the brick used in the pavement. The advantages of the block-size to the manufacturer are that there are fewer pieces to handle; and in the pavement the blocks chip or spall on the edges less than the bricks, particularly if the filler is not rigid (see § 773). The manufacturer of the block usually places building brick in that part of the kiln in which it is difficult to burn blocks thoroughly (the bottom of a down-draft kiln), a process which decreases the per cent of blocks unsuitable for paving purposes, and at least partially eliminates the second advantage of the building-brick size as above. In the early history of brick paving, bricks were most in favor; but now the blocks are most common. Apparently the introduction of the blocks is due, at least in part, to the fact that in the ordinary method of testing the bricks or blocks by tumbling in a cylinder (§ 740), the bricks lose a greater per cent of their weight than do the blocks, and consequently manufacturers preferred to submit blocks rather than bricks for a competitive test, particularly as in the early history of testing clay paving-material specifications made no distinction between bricks and blocks in the loss permissible (§ 748).

Unfortunately the size of building bricks and also of paving blocks varies considerably in different parts of the country. Uniformity of size is very desirable for convenience in making repairs. Sizes of bricks and blocks range all the way from 2 × 4 × 8 inches to 4 × 5 × 10 inches, but the maximum is seldom more than 3 × 4 × 9 inches. There is no conventional line by which to distinguish bricks from blocks; but as a rule "paving brick" are about 2½″ × 4″ × 8½″ and "paving blocks" 3″ × 4″ × 9″.

726. Form of the Brick. Early in the history of the paving-

brick industry a number of odd shapes were upon the market, but they have all been abandoned; and at present the only variations from the form having flat sides and square corners are: (1) rounded corners, to prevent chipping; (2) grooves on the sides and ends, to increase the holding power of the material used to fill the joints between the bricks (§ 773); and (3) raised letters or buttons on the side, to hold the bricks apart to facilitate the introduction of the joint filler.

727. Rounded corners are very common, the radius of the corner varying from one to three eighths of an inch. The rounding of the corner decreases the loss during the first part of the test of the brick in the rattler (§ 740) and also diminishes the chipping during its earlier use in the pavement; but the rounded corner increases the initial roughness of the pavement, and makes it at the beginning what it would otherwise have become only after a considerable use, if ever. The rounded corner is a disadvantage, whatever the material with which the joint is filled (§ 773), since it gives a thin edge to the filling which easily crumbles or chips off. The introduction of the rounded corner was due, in part at least, to the desire of the manufacturer to make a brick that would more readily pass the usual rattler test; and if this test had consisted in determining the loss in a certain number of revolutions after, say, an initial 500 revolutions, this tendency would probably not have occurred. The corner is usually rounded during the re-pressing, which disturbs the initial bond of the clay and weakens the brick, the amount of this weakening varying with the amount of the disturbance and with the character of the clay. The round corner is of doubtful value.

728. Fig. 122, 123, and 124 shows three forms of the grooves employed to facilitate the introduction of the joint filler and to increase its holding power. The depth of the groove differs with the maker, but is usually about $\frac{1}{8}$ to $\frac{3}{16}$ inch deep. The arrangement of the grooves in Fig. 122 is quite objectionable, since the brick spalls off from the edge down to the groove, particularly when the joints are filled with sand. The form shown in Fig. 123 is better than that in Fig. 122, since the vertical grooves facilitate the introduction of the joint filler. It would be still better, if the vertical grooves were continuous across the face of the brick. The

form shown in Fig. 124 is perhaps a little less objectionable than that in either Fig. 122 or 123. All three of the preceding forms often have the name of the manufacturer in sunken letters in the sides of the brick—partly for advertising purposes and partly to increase the holding power of the material used to fill the joints. The grooves and also the sunken letters are added in re-pressing,

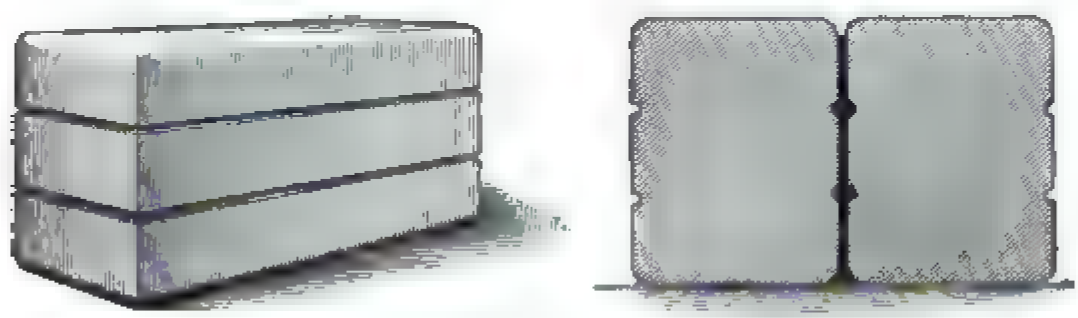

FIG. 122.—GROOVED PAVING BLOCKS.

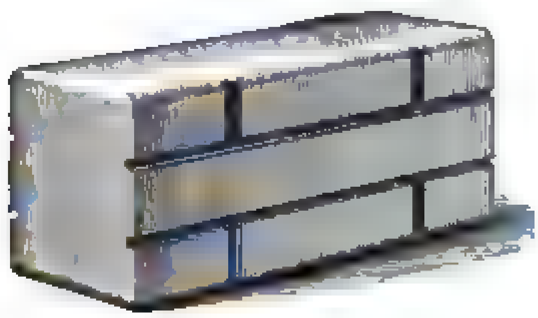

FIG. 123.—GROOVED PAVING BLOCKS.

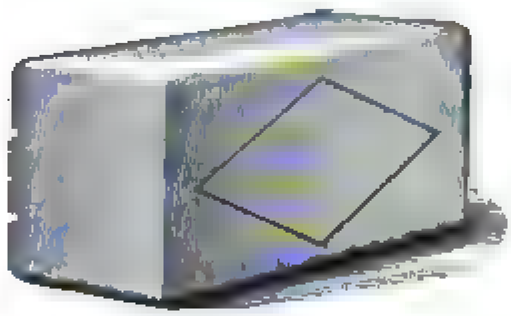

FIG. 124.—GROOVED PAVING BLOCKS.

a process which breaks the original bond of the clay—at least to some extent,—and therefore weakens the brick.

One object of the grooves is to facilitate the introduction of the joint filler. Practically the only materials employed to fill the joints are sand, tar, and hydraulic cement; and no difficulty is experienced (when proper methods are employed—see § 773) in filling the joints with any of these materials.

Another object of the grooves and of the sunken letters is to obtain a keying or locking action of the joint filling; but it does not appear that this is either needed or does any good. The resistance to shearing of the portion in the grooves is small in comparison with the adhesion of the joint-filling material to the side of the brick.

729. The raised letters or buttons are to facilitate the introduction of the joint filler; but with the most regular re-pressed paving blocks or bricks the joints when the bricks are laid as close as possi-

ble are always sufficiently open to permit the introduction of the joint filler. Needlessly wide joints are objectionable, since the material used in filling the joints is not likely to be as durable as the brick itself, and hence the thinner the joints the better. With bricks having a wearing face 3 × 9 inches and joints $\frac{1}{8}$ inch wide, the joints constitute 5 per cent of the surface of the pavement, and $\frac{1}{4}$-inch joints will occupy 10 per cent of the surface.

730. The value of the grooves and of the recessed letters, as also of the raised letters and buttons, can be better understood after the consideration of the purposes of filling the joints and of the materials used—see § 773–80.

731. Requisites for Paving Brick. The brick should be reasonably perfect in shape, should be free from marked warping or distortion, and should also be uniform in size, so as to fit closely together and make a smooth pavement. A good paving brick should be hard so as to resist the crushing action of the wheels of vehicles, and tough so as to resist the abrading action of traffic. Any particular brick should be homogeneous in texture and should be free from lamination or seams, so as to wear uniformly; and all the brick used in a pavement should be of the same grade so that the pavement may wear evenly.

732. Testing the Brick. It is important to have a definite method of testing the qualities of any artificial material, since then all parties may know exactly the grade called for, and since the results obtained by different observers with different materials may be compared. This is particularly true of brick, since the clays differ greatly in quality and also since a slight variation in each step of the manufacture materially affects the result. Definite methods of testing paving brick are less than ten years old, and probably the best method has not yet been discovered; but in the past five years methods have been developed which give fairly satisfactory and definite results. Several tests formerly employed have now been practically abandoned; but for the sake of completeness these will be briefly considered. The object of testing paving brick is two-fold: (1) to determine whether the material is suitable for use in a pavement; and (2) to enable comparisons to be made between different classes of brick.

733. General Appearance. A critical examination of a paving

brick by the experienced eye aided by a hand hammer is an excellent method of determining the relative merits of different bricks of a particular kind; but unfortunately experience with one make is not of much value with brick made by a different process or of a different kind of clay, and further the results by this method of testing admits of no numerical evaluation or even of being described accurately. It is a method of selecting or inspecting rather than of testing.

The brick should have reasonably flat sides and square corners. They should be nearly uniform in size, since the unduly large size indicates under-burned or soft brick, and the unduly small size usually indicates over-burned or brittle brick. However, as most paving brick are die-molded and as the die wears larger by use and must ultimately be replaced by a new one, a change of size from this cause must not be confused with that due to deficient or excessive burning. The edges of the brick should be smooth and free from serrations or "ragging," due to friction in the die; and the "kiln marks;" or impressions from the over-lying brick in burning, should not be over one eighth of an inch. The quality of the brick can be judged by striking it a sharp blow with a hand hammer, or by striking two together, or by dropping the flat side of one upon another.

The interior of the brick should be homogeneous, free from uncrushed or lumpy material, especially if such material is not united by vitrification with the balance of the material of the brick. The brick should be vitrified clear through to the center; and should contain neither unfused spots, which indicate sand or fire clay, nor glassy or spongy spots, which indicate imperfect crushing and mixing of some fusible mineral in the clay. The structure should be free from "shakes" or marked laminations. Fire cracks, caused by too rapid firing, if small and superficial, are not of much importance; but they should be limited in number and extent. There should be no lumps of lime, due to the presence of limestone pebbles in the unburned clay, since these will slake when the brick becomes wet and probably disrupt it.

734. Color. The color is no criterion of the value of a paving brick, when comparing brick of various makes; but, in inspecting brick from a single factory, the color will usually furnish a fairly

safe guide as to the relative hardness, when the inspector is thoroughly acquainted with the particular manufacture. The knowledge gained regarding the relation of color and quality in inspecting one make of brick, however, can seldom be used with that of another make from a different locality, as clays vary greatly in kind and degree of color. The popular belief is that hardness is proportional to the darkness of the color of the brick, and that light color is prima facie evidence of softness. As a rule the impure fire clays make excellent paving material, although the brick are light colored, usually buff, while shale brick are red or brown. For a particular clay, the color of the bricks indicates the degree of heat they have received, provided they were burned with the same fuel and under the same conditions; and ordinarily the higher the heat the darker the color, and presumably the better the brick. The uniformity of the color of the interior of the brick is more important than the color of the exterior.

The color of the outside of the brick is sometimes valueless owing to the sand employed to prevent sticking in the kiln, or to the effect of sulphur in the coal used in burning, or to salt glazing. Salt glazing is a trick occasionally employed to give a dark gloss to the outside which is very attractive to the superficial observer, but which is practically worthless, since it is only skin deep and soon wears off. Salt glazing makes it more difficult to detect soft brick, and should never be allowed on paving brick.

735. Specific Gravity. In a general way, the more dense a brick the harder and stronger it is; and consequently early in the history of brick testing it was believed that a knowledge of the specific gravity would be of value in judging of the quality of a paving brick. It is now known that the specific gravity reveals nothing not determined by other tests; and further that the density depends upon the character of the clay, the kind of fuel, etc., and in no way measures the quality of the product. The specific gravity may be computed by the formula:

$$\text{Specific gravity} = \frac{Wa}{Ws - Wi},$$

in which Wa represents the weight of the dry brick in air Ws the weight of the saturated brick in air, Wi the weight of the brick

immersed in water. The specific gravity of shale brick ranges from 2.05 to 2.55, and usually from 2.20 to 2.40; and that of brick made from impure fire clay ranges from 1.95 to 2.30, and generally from 2.10 to 2.25.

736. Crushing Strength. The results for the crushing strength vary more with the details of the method employed than any other test of paving brick. There is no standard method of making this test. (1) Some experimenters test cubes, others half brick, and still others whole brick; (2) some grind the pressed surfaces accurately to planes, some true the surface up by putting on a thin coat of plaster of paris, while still others level up with blotting paper, card board, etc.; (3) some test the brick on end, some on edge, and others flatwise. For experimental data showing the marked effect of the different methods of testing, see the author's Treatise on Masonry Construction, page 41–45.

Tests on cubes cut from paving brick show that the best paving brick have a crushing strength of 10,000 to 20,000 pounds per square inch. This is the crushing strength when the load is applied uniformly over the surface of the test specimen; but if the pressure is applied to only a small part of the upper surface of a brick, the strength will be much greater.* Any brick that is likely to be accepted for paving purposes by any of the tests hereafter described, is in no danger of being crushed by the pressure of the wheel of a vehicle. For example, the surface of contact between a wheel having a 1½-inch tire loaded with half a ton is about one half square inch, which gives a pressure on the brick of only about 2,000 pounds per square inch.

If the crushing strength could be easily and accurately found, it would be of value in determining the relative strength, and hence would be useful in comparing the quality of different brick; but owing to the difficulty of making the experiments and to the uncertainty of the results, the test has been abandoned.

737. Absorption Test. In the early days of the paving brick industry, many of the brick used were so porous and brittle that it was feared they would be disintegrated by the action of frost; and consequently the absorption test was employed to eliminate porous

* See Baker's Masonry Construction, p. 190.

brick. Subsequent tests by repeatedly freezing and thawing paving bricks showed that any brick which was likely to be accepted for paving purposes would not be appreciably injured by the action of frost. There are probably two elements that prevent frost from seriously injuring even a soft paving brick; viz.: (1) the cushioning effect of the air remaining in the pores of the brick, and (2) the strength of the brick may be greater than the disrupting effect of the frost. Alternate freezing and thawing might injure a non-vitrified brick, which is not only very porous but is also deficient in strength; but such a brick would be rejected for paving purposes as the result of a casual inspection. The absorption test is no longer regarded of importance as measuring the ability of the brick to resist freezing and thawing.

The absorptive power of a brick is now regarded only as a measure of the porosity of the brick, i. e., of the degree of vitrification. In the first stages of burning, free water is driven off with no perceptible effect upon the clay; in the second stage, the water of constitution of the clay is expelled, leaving the clay in a very porous and spongy condition. At this time the strength of the clay is at its lowest point, and the porosity is at its greatest development; while the chemical combination between the clay and the other minerals has not yet begun. The partially burned brick can be easily crushed to a powder; and if wetted and frozen, it becomes a mass of gritty mud on thawing. But if the temperature of burning is increased, the clay decreases in porosity and increases in strength; and the walls of the pores fuse and close in on one another, gradually expelling the gases which filled them and obliterating the original porous structure. As the cell walls collapse and tend to expel the gases from the pores, these gases encounter increasing difficulty in finding their way out to the surface; and some of these gases become imprisoned in the clay, and as the latter becomes more and more fluid or viscous with the rising heat these volumes of gases expand and create little spherical cavities or vesicles in the clay body. So it always happens that in burning a piece of clay-ware two opposing forces are at work at the conclusion of the burning. One is the obliteration of the pore structure, accompanied by the expulsion of the gases, which produces greater density and strength; and the other is the expansion of imprisoned volumes

of gases, which produce a cindery or vesicular structure, and decreases the density and strength. Therefore there is a point of maximum strength, and continuing the burning beyond this decreases the porosity and also the strength. In the early history of the paving-brick industry, it was held that the less the absorption the better the brick; but the above explanation shows that there is a degree of porosity corresponding to maximum strength. The relation between strength and porosity varies greatly with the character of the clay and with the method of molding. For example, a stiff-mud shale brick has an absorption of 4 per cent and disrupts under the action of frost; while a soft-mud brick made of surface clay will endure with an absorption of 10 or 12 per cent.*

Different bricks vary widely in their rate of absorption. For example, one brick absorbed in one day 80 per cent of its total amount, while another absorbed only 8.7 per cent; and two other specimens absorbed 71.8 and 19.5 per cent respectively in the same time.† The absorption of whole brick is slightly less than that of half brick, and the absorption of half brick is considerably less than that of small chips. For the above reasons and for other minor ones, results for the absorptive power are likely to be untrustworthy.

738. The absorption test is capable of giving data of value in regard to the degree of vitrification, but to be generally useful as a standard for grading brick the limiting per cent of absorption should be determined for each variety of brick, a task which is impracticable, except where there are only a few brands of brick upon any particular market.

Hence this test is valuable to a user of brick only as a check upon the uniformity of a particular brand. It could be used to exclude any soft and porous brick, but such material would be unhesitatingly rejected on account of its general appearance.

The National Brick Manufacturers' Association recommend that when this test is employed, it be made according to the following method: ‡

* Report of Paving Brick Commission of National Brick Manufacturers' Association, p. 62–63. T. A. Randall & Co., Indianapolis, Ind.

† *Ibid.*, p. 70, Table XX.

‡ *Ibid*, p. 83.

"1. The number of bricks constituting a sample for an official test shall be five.

"2. The bricks selected for conducting this test shall be such as have been previously exposed to the rattler test. If such are not available, then each whole brick must be broken in halves before the test begins.

"3. The bricks shall be dried for forty-eight hours continuously, at a temperature of 230 to 250 degrees Fahr., before the absorption test begins.

"4. The bricks shall be weighed before wetting, and shall then be completely immersed for forty-eight hours.

"5. After soaking, and before re-weighing, the bricks must be wiped till free from surplus water and practically dry on the surface.

"6. The samples must then be re-weighed at once. The scales must be sensitive to one gram.

"7. The increase in weight, due to absorption, shall be calculated in per cents of the dry weight of the original bricks."

Shale paving bricks when tested as above usually show less than 2 per cent of absorption, some of the best ranging from 0.75 to 1.50; less than 0.5 probably indicates an over-burned and brittle brick. Good paving brick made of impure fire clay rarely absorb less than 2.5 per cent, and often over 5 per cent.

To apply this test to determine uniformity of quality, it will be necessary to establish limits of the absorption. This may be done by inserting in the specifications a clause somewhat like the following:*

"At the time of submitting bids, the bidder shall furnish twenty-five bricks of the make specified in his bid, on which a rattler test and an absorption test shall be made. A requirement of the bricks furnished for the pavement will be that their absorption tests shall fall within the following limits: When the result of the absorption test of the sample bricks is below 2 per cent, the limits shall be ¾ per cent less and 1 per cent more than the sample; when between 2 per cent and 5 per cent, the limits shall be 1 per cent less and 1½ per cent more than the sample."

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*Report of Committee on Brick Tests and Specifications, Proc. Illinois Society of Engineers, 1901, p. 90.

739. Transverse Strength. This is determined by resting the brick upon two knife-edges and applying a steady pressure on the upper side of the brick through a third knife-edge placed midway between the other two. The results are expressed in terms of the modulus of rupture, which is computed by the following formula:

$$R = \frac{3\,W\,l}{2\,b\,d^2}$$

in which R represents the modulus of rupture in pounds per square inch, W the breaking load in pounds, l the distance between supports in inches, b the breadth of the brick in inches, and d the depth of the brick in inches. The brick may be tested edgewise or flatwise, although the former is usually the better method, since then W is larger. The knife-edges should be rounded transversely to a radius of about one sixteenth of an inch and longitudinally to a radius of about 12 inches, to secure better contact and to prevent the brick from being crushed at the edges. Some authorities recommend grinding opposite edges of the brick to parallel planes, but this is a useless expense. If the brick is warped, the contact between the brick and the knife-edges can easily be made entirely satisfactory by placing pieces of metal under the blocks carrying the lower knife-edges, or by shifting the brick longitudinally, or by turning it.

The modulus of rupture of bricks that have given excellent service in a pavement varies from 1,500 to 3,500 pounds per square inch, usually from 2,000 to 3,000. Owing to apparently unavoidable variations in the structure of the brick it is not possible to attain closely concordant results in making this test; and with the utmost care in selecting the brick and in making the tests, the variation from the mean ranged from 8 to 30 per cent, and on the average was about 20 per cent.*

The cross-breaking test furnishes a means of comparing the toughness of various kinds of paving brick. The uniformity of the results for any particular kind of brick indicates its structural soundness, freedom from air checks, etc., and shows whether the

* Report of Paving Brick Commission, p. 90, Table XXXII.

material has been properly treated in the various stages of manufacture. The transverse strength indicates the resistance of the brick to cross breaking when laid in the pavement on an unyielding and uneven surface; but this element is not entitled to much consideration, since brick are seldom thus broken in the pavement, at least not until nearly worn out.

The test is comparatively easy to make, and is a valuable check upon the rattler test (§ 740).

740. Impact and Abrasion Test. This test is made by rolling or tumbling the brick, with or without pieces of iron, in a foundry rattler or revolving cast-iron barrel. This test is often called the rattler test. It is the crucial test of a paving brick and greatly exceeds in importance all the other tests combined. It is pre-eminently the test that will show whether a brick will prove satisfactory in service, and which of two or more samples will be the more enduring in the pavement. This test imitates more closely than any other the impact due to the horse's hoofs and shoes, and to the bumping of the vehicle wheels, and also the abrasion due to the slipping of the horse's feet and the sliding of the wheels. The tumbling, rolling, and sliding of the brick and iron over each other rapidly wear off the brick, and closely represents the treatment a brick will receive in the pavement. The result is jointly dependent upon the toughness of the brick—its ability to resist shock,—and its hardness—its ability to resist abrasion.

To make this test of any scientific value in determining either the probable behavior of the material in the pavement or the relative merits of different brick, it is necessary to have some standard method of conducting the experiments. Unless some standard is established, this method can be employed only to select the best of a number of samples tested under exactly the same conditions. Several methods of standardizing this test have been proposed.

741. The first attempt to standardize the rattler test was made by the author.* Brick that had seen service in a pavement and pieces of well known natural stones used for paving purposes, together with small pieces of scrap cast-iron, were rolled in a rattler.

* Durability of Paving Brick, by Ira O. Baker. 46 p. 5″×8″. T. A. Randall & Co., Indianapolis. Ind., 1891.

By this method any new paving brick could be compared with an absolute standard by securing samples of the natural stones used, and testing the brick and the stone under similar conditions. Shortly after being proposed, this method was quite widely adopted; but did not give satisfactory results, chiefly because the original experiments were made with a rattler having wooden staves, while subsequent tests were made with rattlers having cast-iron staves. The method was objectionable on account of the trouble and expense of preparing the test pieces of natural stone.

Later the author made a series of tests using 2-inch cubes of brick and stone with foundry "stars" in a rattler having metal sides; but it was found that the results varied so greatly with the form, size and speed of the rattler as to make them of no great value.

742. *Orton's Method.* From 1895 to 1897, Prof. Edward Orton, Jr., of the Ohio State University, under the auspices of the National Brick Manufacturers' Association,* conducted a very extensive series of experiments upon the effect (1) of varying the form, size, and speed of the rattler; (2) of varying the quantity of brick in the rattler; (3) of successive periods of rattling; (4) with and without miscellaneous pieces of cast iron; and (5) with and without blocks of natural stone. Based upon these experiments a series of recommendations were made to the National Brick Manufacturers' Association which were adopted in 1897† as the standard method of making the impact and abrasion test of paving brick, and which were largely used for two or three years. This test was abandoned because of its failure to sufficiently discriminate the good and the poor paving brick, and also because of the great variation of duplicate tests. The distinguishing characteristic of this method was that only brick were placed in the rattling chamber.

743. In this method bricks or blocks equal to 15 per cent of the volume of the rattling chamber were placed in the standard rattler (see paragraphs 1 and 2, § 745) and revolved at the rate of 30 revolutions per minute for 1 hour. Under these conditions the loss of good paving brick varied from 15 to 25 per cent.

744. *Talbot's Method.* From 1895 to 1899 experiments were

*Report of Paving Brick Commission. 110 p. 6" × 9". T. A. Randall & Co., Indianapolis, Ind., 1897.

† *Ibid.*, p. 57–58.

conducted at the University of Illinois under the direction of Prof. A. N. Talbot to determine the best composition of the abrasive material.* From these experiments the conclusion was drawn that the best results were obtained by the use of a mixed charge of two sizes of cast-iron blocks † the distinguishing characteristic of this method of conducting the abrasion and impact test is the use of a charge of abrasive material composed of two sizes of moderately heavy cast-iron blocks. The large blocks give chiefly impact and the small ones principally abrasion. The relative amount of these two forms of wear may be varied by varying the proportion of the two sizes. This method has been employed by a number of experimenters, and it has been shown conclusively that it is superior to that in which brick alone was used in the rattler for the following reasons: (1) it more nearly represents the condition of service in the pavement, (2) it gives more uniform results, and (3) it is more sensitive in differentiating hard and soft brick.

745. *N. B. M. A. Standard.* In February, 1901, the National Brick Manufacturers' Association modified its previous standard (§ 742) by adopting Talbot's form of abrasive material, and published ‡ the following specifications for the standard method of conducting the rattler test of paving brick, which have been widely adopted.

1. *Dimensions of the Machine.* The standard machine shall be 28 inches in diameter and 20 inches in length, measured inside the rattling chamber. Other machines may be used, varying in diameter between 26 and 30 inches, and in length from 18 to 24 inches; but if this is done, a record of it must be attached to the official report. Long rattlers must be cut up into sections of suitable length by the insertion of an iron diaphragm at the proper point.

2. *Construction of the Machine.* The barrel may be driven by trunnions at one or both ends, or by rollers underneath, but in no case shall a shaft pass through the rattler chamber. The cross section of the barrel

* The Technograph, University of Illinois, 1895–96, p. 93–100; 1897–98, p. 16–23. Proc. Illinois Society of Engineers, 1897, p. 82–86; 1898, p. 174–76, p. 181–86; 1899, p. 232–34; 1900, p. 107–08; 1901, p. 83–91.

† For the dimensions of the two sizes and the proportions of each, see paragraphs 3 and 4, § 745.

‡ Abridged Report of the Committee on Technical Investigation; an official pamphlet, 10 p. 6″×9″.

shall be a regular polygon having fourteen sides. The heads shall be composed of gray cast iron, not chilled nor case-hardened. The staves shall preferably be composed of steel plates, as cast iron peans and ultimately breaks under the wearing action on the inside. There shall be a space of one fourth of an inch between the staves for the escape of the dust and small pieces of waste. Other machines may be used having from twelve to sixteen staves, with openings from one eighth to three eighths of an inch between staves, but if this is done a record of it must be attached to the official report of the test.

3. *Composition of the Charge.* All tests must be executed on charges containing but one make of paving material at a time. The charge shall be composed of the bricks to be tested and iron abrasive material. The brick charge shall consist of that number of whole bricks or blocks whose combined volume most nearly amounts to 1,000 cubic inches, or 8 per cent of the cubic contents of the rattling chamber. (Nine, ten, or eleven are the number required for the ordinary sizes on the market.) The abrasive charge shall consist of 300 pounds of shot made of ordinary machinery cast-iron. This shot shall be of two sizes, as described below, and the shot charge shall be composed of one fourth (75 pounds) of the larger size and three fourths (225 pounds) of the smaller size.

4. *Size of the Shot.* The larger size shall weigh about 7½ pounds and be about 2½ inches square and 4½ inches long, having edges rounded to a radius of about ½ inch. The smaller size shall be 1½ inch cubes, weighing about seven eighths of a pound each, with square corners and edges. The individual shot shall be replaced by new ones when they have lost one tenth of their original weight.*

5. *Revolutions of the Charge.* The number of revolutions of the standard test shall be 1,800, and the speed of rotation shall not fall below 28 nor exceed 30 per minute. The belt power shall be sufficient to rotate the rattler at the same speed whether charged or empty.

6. *Conditoin of the Charge.* The bricks composing a charge shall be thoroughly dried before making the test.†

7. *Calculating the Results.* The loss shall be calculated in percentages of the weight of the dry brick composing the charge, and no

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* It has been proposed to use chilled steel shot, which have practically no wear, and thereby to save the expense of re-placing and of frequently re-weighing the cast-iron shot.

† "Soft brick saturated with 8 per cent of water lost only 67 per cent as much as brick from the same lot tested dry." It has been clearly proved that dry brick lose more than wet ones, but the reason for this difference has not been established. It is reasonable to suppose that different kinds of brick having different percentages of absorption should have different losses for different degrees of moisture.

result shall be considered as official unless it is the average of two distinct and complete tests, made on separate charges of brick.*

746. Fig. 125 shows a common form of the standard rattler. The chamber on each side of the partition is of the standard form, and consequently two lots of brick may be tested at the same time.

Fig. 126 shows a form of rattler, designed at Purdue University, which permits easy access to the rattling chamber without the trouble of removing a stave. The rattler is enclosed in a dust-proof case made of sheet iron and having felt-packed joints. A door

FIG. 125.—RIEHLÉ'S STANDARD RATTLER.

in the lower part of the case provides for the removal of a pan which receives the dust and chips from the rattler.

747. The per cent of loss in the impact and abrasion test will depend upon the care employed in culling the brick and in select-

* There is considerable difference in practice as to the method of considering broken brick, some experimenters counting all pieces weighing less than 1 pound as abraded material; while others put the limit at half a pound. The latter is apparently the more common.

ing the samples, as well as upon the character of the brick. To show the results that may be expected, the following data obtained by a city in Ohio in the ordinary course of business are given. The samples were selected from material after delivery upon the

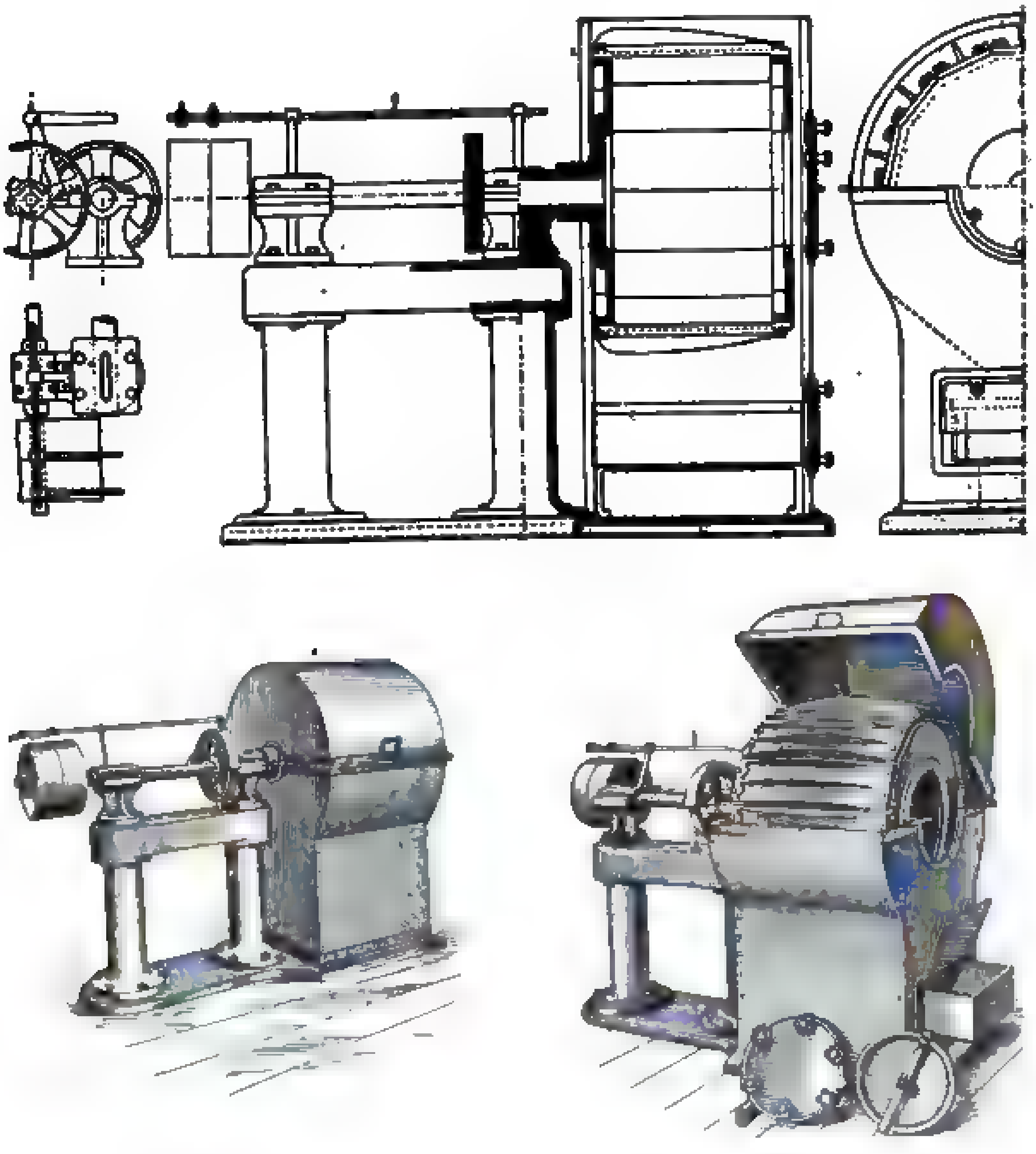

FIG. 196.—PURDUE RATTLER FOR TESTING PAVING BRICK.

street, by a representative of the city. The tests were carefully made according to the N. B. M. A. standard as above. The material was in the form of blocks approximately 3″ × 4″ × 9″. The average of the losses of fourteen samples was 18.97 per cent,

the range being from 15.60 to 24.35 per cent. The samples represent some of the best paving material in Ohio. Omitting the product of one manufacturer, the average of the losses was 18.57 per cent, and the range was from 15.60 to 21.62 per cent, the last being the loss of a well-known standard paving block. Of the product of the thirteen manufacturers, nine had a loss of less than 20 per cent, seven less than 19 per cent, four less than 18 per cent, and two less than 16 per cent. Eleven lots of the best grade of blocks gave an average loss of 15.60 per cent with a range for the average of duplicate tests from 12.25 to 18.70 per cent. Individual tests of these blocks ran as low as 10.3 per cent, and duplicate tests of samples selected by the manufacturer (not included above) gave losses of 11.76 and 11.92 per cent respectively. Ten samples of the blocks having the greatest losses gave an average of 21.62 per cent with a range from 14.90 to 34.77; and samples selected by the manufacturer (not included above) gave losses of 11.14 and 13.73 per cent respectively.

Ten lots of blocks tested in an Illinois city gave an average loss of 18.34 per cent with a range from 15.4 to 24.6 per cent; and, omitting the largest result, the average was 17.64 per cent with a range from 15.4 to 21.2 per cent. Of the ten kinds of blocks, two had losses of less than 16 per cent, four less than 18, six less than 19, and eight less than 20 per cent.

A few other scattering results seem to show that the above are fairly representative of the above localities; but these localities are favored in native material suitable for making paving brick and also in the attention given to that industry, and consequently other localities may not expect as favorable results. The Second Annual Report on the Highways of Maryland contains, on pages 118 to 120, the results of one hundred and twenty N. B. M. A. rattler tests on paving bricks, some of the samples having been selected by the City Engineer of Baltimore and some by the manufacturers. The results by localities are as follows, in the order of the quality of the bricks: Eleven lots from Ohio gave a mean loss of 18.2 per cent with a range from 16.2 to 20.0; ten lots from West Virginia had a mean loss of 22.7 per cent and a range from 17.0 to 35; twenty-four lots from Pennsylvania showed a mean loss of 26.8 per cent and a range from 18.6 to 55.8, and omitting

two lots the average is 24.8 per cent and the range from 18.6 to 34.2; and nine lots from Maryland gave an average loss of 32.1 per cent with a range from 25.3 to 48.7, and omitting one result the mean is 26.3 per cent and the range from 25.3 to 37.6.

748. All of the above data are for blocks approximately 3″ × 4″ × 9″. Bricks approximately 2″ × 4″ × 8″ will lose from 2 to 6 per cent more than the above blocks; but not enough data have been accumulated to determine with any accuracy the effect of size upon the loss in the rattler test.* It is difficult to secure the specimens necessary in making the comparison.

749. A study of the details of the experiments referred to above, indicates that an occasional manufacturer can furnish paving blocks giving a loss of 15 per cent or even less; but whether it is wise so to specify will depend upon the service required and upon the cost of different grades of paving blocks. A severe specification will require more careful culling of the product of the kiln and will also limit competition,—both of which demands will increase the cost. The limit to be specified in any particular case will depend upon the special conditions.

750. The N. B. M. A. standard rattler test is defective in that it determines only the average loss of two charges of brick and gives no information as to the uniformity of the quality of the individual bricks. Uniformity of wear is nearly as important as durability, for a single soft brick soon causes a hole, and the blows of the wheels in dropping into this hole soon destroy the adjacent pavement, however good the brick are. The value of the test would be materially increased, if in specifying the limit for the average loss in the rattler a statement were also made of the amount that the loss of one charge may be permitted to go above or below the average of two. A study of the tests described in the preceding section shows that loss of each charge should not vary from the mean of the two by more than 10 or 12 per cent of that result. This modification would add nothing to the cost of the test or to the time required in making it.

The value of the test could be further increased by determin-

* For a few data on the relative losses of different sizes when tested by the former N. B. M. A. standard, see Report of Paving Brick Commission, p. 56.

ing the loss of each individual brick, and specifying a limit to the variation of any brick from the average of the charge. Experiments show that with the best paving blocks the loss of any individual brick will differ 25 to 30 per cent of the mean of the charge from that result. Part of this variation is due doubtless to accidental differences in making the tests, but a large part of it is due to lack of uniformity of the bricks themselves.

To determine the losses of the individual blocks will require the marking of the blocks so that they may be identified after the test is completed. One way of accomplishing this result is to drill holes, say, ¼ inch in diameter, in the side of the block; and another is to mark the brick with a cold chisel, in which case they must be examined at intervals during the test and be re-marked as the original marks wear off.

751. *Talbot-Jones Method.* In February, 1899, Mr. Gomer Jones, City Engineer of Geneva, N. Y., read a paper before the National Brick Manufacturers' Association advocating a method of testing paving brick by clamping them in pockets on the inside of the staves of a rattler, and inserting into this chamber a charge of 1½-inch cast-iron cubes. It was claimed that this method of testing more nearly represented the condition of service in the pavement than either of those described above. The investigation of this method was referred to the Association's Committee on Technical Investigation, which called to its aid a Board of Expert Engineers and conducted a series of experiments with a modification of the Jones rattler, or rather a substitute for it, proposed in 1900 by Prof. A. N. Talbot, and named by the Committee the Talbot-Jones rattler.

The Talbot-Jones rattler consists of a short over-hung cylinder in which the bricks are clamped by bolts between them and bearing on their ends. The bricks are so placed as to form a lining to the cylinder in which the cast-iron cubes are placed. Fig. 127 is a view of the rattling chamber with one end removed, before the bricks have been tested; and Fig. 128 the same after the bricks have been tested. Fig. 129, page 490, shows the details of construction of the rattler. A short sheet-steel cylinder is fastened to a cast-iron face-plate by bent steel bars. The end of the cylinder lacks about ¼-inch of being in contact with the face-plate, the space being left for the

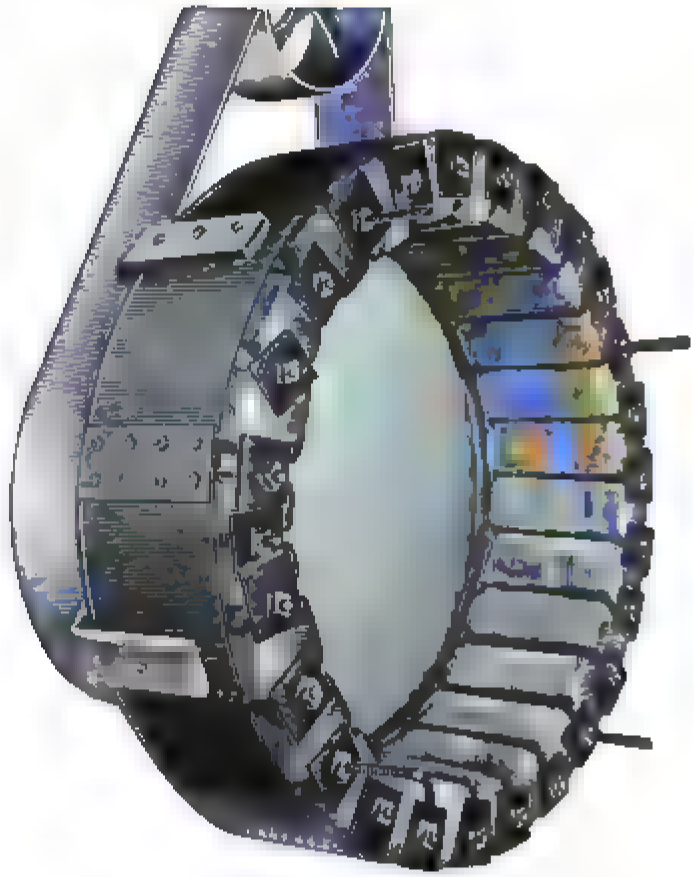

FIG. 127.—TALBOT-JONES RATTLER BEFORE RUNNING.

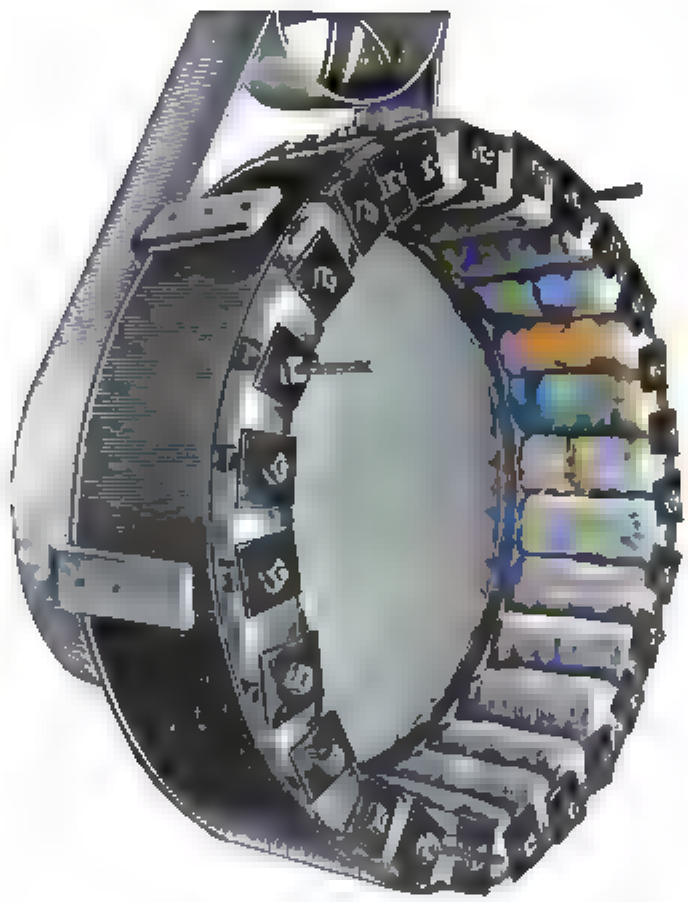

FIG. 128.—TALBOT-JONES RATTLER AFTER RUNNING.

escape of dust and chips. About 1½ inches from the circumference of the face-plate is a T-shaped groove opening to the front in which are placed the heads of the bolts that clamp the bricks in position.

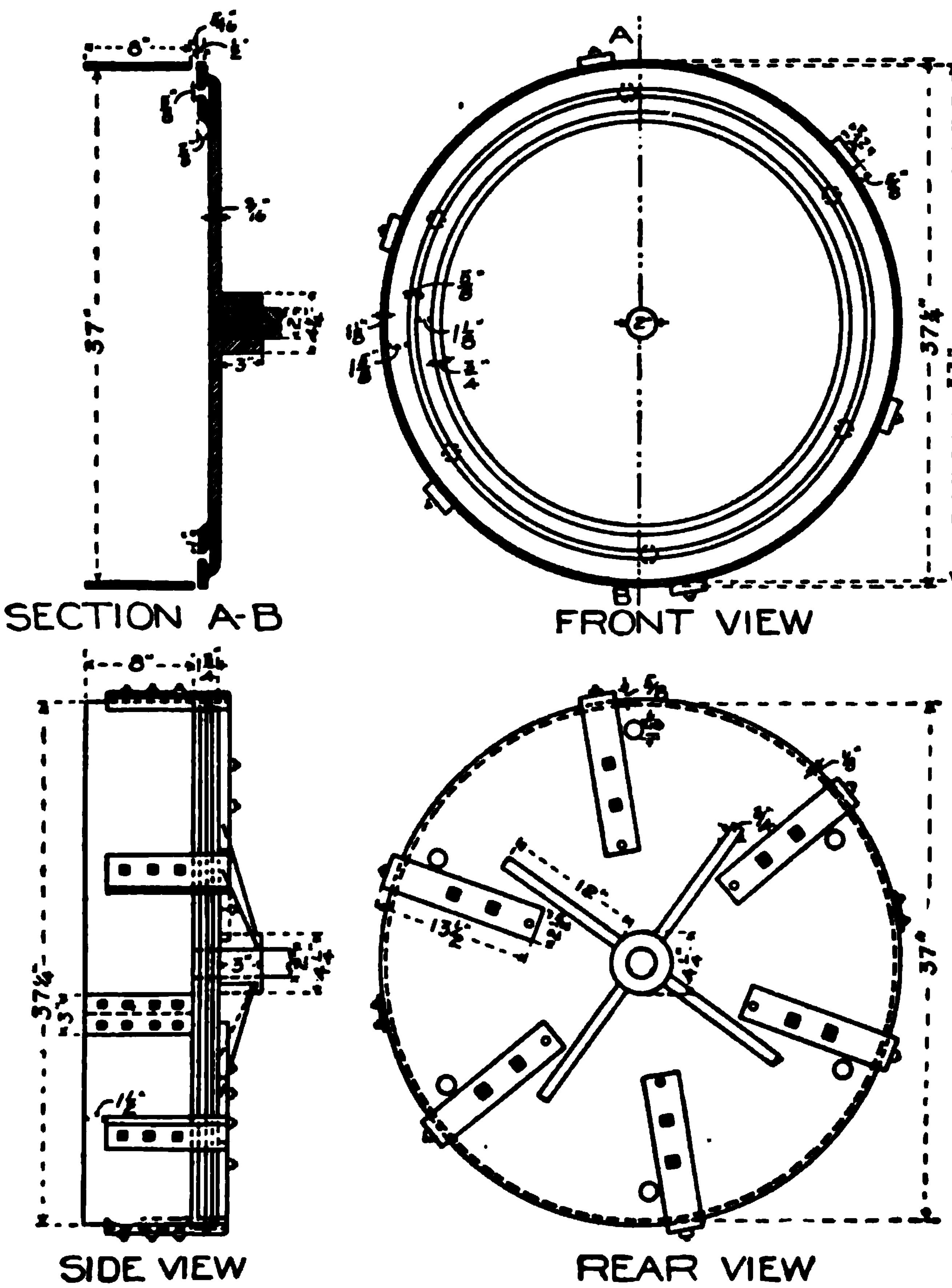

FIG. 129.—DETAILS OF CONSTRUCTION OF TALBOT-JONES RATTLER.

Access to this groove is had through six 1½-inch holes in the back of the face-plate. About 3½ inches from its circumference, the front of the face-plate is recessed about ¾-inch. The lower part of

the back end of the brick is in contact with the face-plate; but, owing to the recess described above, the inner edge of the back end of the brick is unsupported, an arrangement which allows the impact of the iron cubes to have their full effect. Strips of wood are placed between the outer edges of the bricks to keep them the right distance apart and to aid in keeping them in position. After the bricks are in place, the free end of the cylinder is closed with a wood disk, which is fastened in place by the four long bolts shown in Fig. 128 and 129. In the center of the large wood disk is a small opening for inserting the cast-iron cubes and for viewing the progress of the experiment.

752. This machine is still in the experimental stage, having been used only by Prof. Edward Orton, Jr., of Ohio State University, in some tests made for the Technical Committee of the National Brick Manufacturers' Association, and by Messrs. John Barr and C. W. Malcolm, Civil Engineering students, University of Illinois, in thesis work;* and consequently the best relations have not been determined.

Professor Orton used 60 pounds of $2\frac{3}{8}$-inch cast-iron cubes and 90 pounds of $1\frac{1}{2}$-inch cubes, and ran the machine at 41 revolutions per minute for 3,000 revolutions. As a result of a series of experiments with different spaces between the brick, he recommended a space of 1 inch. Messrs. Barr and Malcolm used $1\frac{1}{2}$-inch cast-iron cubes. They used the same composition of abrasive material and ran the machine at the same speed as Professor Orton, but used $\frac{1}{4}$-inch spacing.

The size of the cubes determines the relative intensity of the impact and abrasion; and the size of the crack between the blocks, together with the speed, governs the height to which the abrading material is carried, and consequently has a marked influence upon the amount the blocks lose.

753. Professor Orton found the average loss of six different kinds of paving blocks to be 15.3 per cent by the N. B. M. A. standard test, and 12.8 per cent by the Talbot-Jones process as above.

Messrs. Barr and Malcolm found the average loss of two kinds

* Bachelor's Theses, University of Illinois Library, 1902.

of paving blocks by the N. B. M. A. standard test to be 21.2 per cent and by the Talbot-Jones process as above to be 5.1 per cent; and with bricks $2\frac{1}{2}'' \times 4'' \times 8\frac{3}{4}''$ they found the loss by the N. B. M. A. standard test to be 24.2 per cent, and by the Talbot-Jones process 9.4 per cent.

754. The essential difference between this process and the preceding one is that in this only one surface of the brick is exposed to action, while in the preceding method all sides are subjected to wear. Many believe that the Talbot-Jones test more nearly approximates the conditions in the pavement than the N. B. M. A. standard; but owing to the absence of any lateral support of the brick in the Talbot-Jones rattler, the former does not very closely represent the conditions in the pavement. However, the wear, for some grades of brick at least, is strikingly similar to that in the pavement. The Talbot-Jones method gives a considerably wider range between good and poor brick than does the N.B.M.A.standard.

The time required by the Talbot-Jones process is twice that required by the standard process for one charge; but to obtain the average result required by the latter method, a time equal to one test with the former machine is required. The number of brick treated in one test with the Talbot-Jones machine is substantially the same as in two tests by the N. B. M. A. standard. The power consumed in revolving the rattler and its charge is a little less in the Talbot-Jones than in the standard process. It is easier to determine the losses of individual bricks with the Talbot-Jones form than with the standard rattler. The skill required in conducting the test by the Talbot-Jones process is distinctly more than for the N. B. M. A. standard, as the preparation of a charge for rattling requires much more care and discretion; and the supplies consumed are more expensive, as there are many more bolts under continual wear and many more small accessories to provide, such as wedges, gaskets, washers, clips, etc. The iron abrasives worn out are less expensive than those of the standard process. The first cost of the Talbot-Jones machine is greater and the workmanship is distinctly of a better grade than is required for the standard process. The cost of a test by the Talbot-Jones process, however, is somewhat greater in money, time, energy, and skill than the N. B. M. A. standard.

755. The rattler test should be regarded as a mean (1) of determining whether any particular brand of brick meets the specifications and (2) of comparing any new brick with those that have been tested by service in the pavement; but (3) it should not be used to discriminate between two grades of brick differing only slightly in rattler losses, since owing to variations in the quality of different brick from the same lot and to accidental variations in making the test, the rattler can not give mathematical accuracy. Further, the loss in the rattler is the combined loss due to impact and abrasion, and consequently the loss of a brittle brick may be chiefly due to chipping, while that of a soft tough brick may be due principally to abrasion. It is not known that the relative losses due to impact and abrasion in the rattler is the same as in the pavement; and hence for this reason also the rattler should not be used to discriminate between two grades of high-quality paving brick.

756. Service Tests. Three experiments are in progress to determine the relative qualities of paving blocks by actual service in the pavement. Each experiment consists in testing a number of standard grades of paving blocks and then laying short sections of pavement with each of the several kinds.

The first of these experimental sections was laid in May, 1898, in Detroit, Mich., on Franklin Street, between Beallbien Street and the Grand Trunk freight depot. Transverse strips of fourteen kinds of brick were laid in a distance of 222 feet. The blocks were tested by the former N. B. M. A. standard rattler test (§ 742). The foundation was 6 inches of concrete. The sand cushion was 1 inch thick, and the joints were filled with coal-tar distillate No. 6. For a comparison between the results of the rattler tests and a general observation of the effect of three years' wear in the pavement, see *Municipal Engineering*, Vol. 22, pages 283–84, and 363–65. These comparisons fail to show any close agreement between the former N. B. M. A. rattler test and service in the pavement.

The second experiment was inaugurated Oct. 16, 1900, on the driveway leading to the Chicago Avenue pumping station at Chicago, Ill. Nine kinds of paving blocks were laid in a distance of 392 feet. The time is too short and the traffic too light to have yet determined any valuable results.

The third experiment was begun Nov. 2, 1901, on Holiday Street between Fayette and Baltimore Street, in Baltimore, Md. Seven kinds of clay blocks, two kinds of artificial sheet asphalt, one piece of natural rock asphalt, and one sample of creosoted pine blocks, were laid in a distance of 221 feet, the abutting street at each end being paved with Belgian blocks (§ 808). For details concerning the tests of the brick and the construction of the pavement, see Annual Report of the City Engineer of Baltimore for 1901, pages 73–74 and 112. The bricks were tested by the N. B. M. A. standard rattler test, and were laid on a 1½-inch sand cushion resting on new cobble-stone pavement. The joints were filled with sand. After eight months' wear, the fourth best brick block by the rattler test seems to have worn best in the pavement, and the best brick block in the rattler test seems to be among the poorest in the pavement.

The non-agreement between the results of the rattler test and service in the pavement indicates that the rattler test is not an infallible guide in selecting paving brick; but this disagreement does not prove that this test should be abandoned. The rattler test is the best method known for determining the qualities of paving brick, and possibly it may be ultimately modified so as more closely to agree with results of actual service.

ART. 2. CONSTRUCTION.

757. Thus far, in the history of brick pavements, attention has been centered in the quality of the brick, while comparatively little attention has been given to the details of the construction. A good pavement requires both good material and good construction.

758. FOUNDATION. Each brick should have an adequate support from below, as otherwise the loaded wheels will force it downward and make the surface uneven, a condition which conduces to the rapid destruction of the pavement by the impact of the wheels in passing over the depressions. There are several forms of foundation in common use for brick pavements.

The best foundation is doubtless a bed of concrete laid as described in Art. 2, Chapter XII, pages 367–82. Fig. 130

is a section of a brick pavement having a concrete foundation. In recent years there has been a marked tendency to use concrete for the foundation of a brick pavement; although a brick pavement should have adequate support, and although concrete when properly made makes an excellent foundation, it does not follow that every such pavement should be laid upon concrete,—at least upon a 6-inch layer, as is the common practice. Under certain conditions a layer of macadam may be cheaper and equally effective—see § 562, Art. 3, Chapter XII; and sometimes a layer of

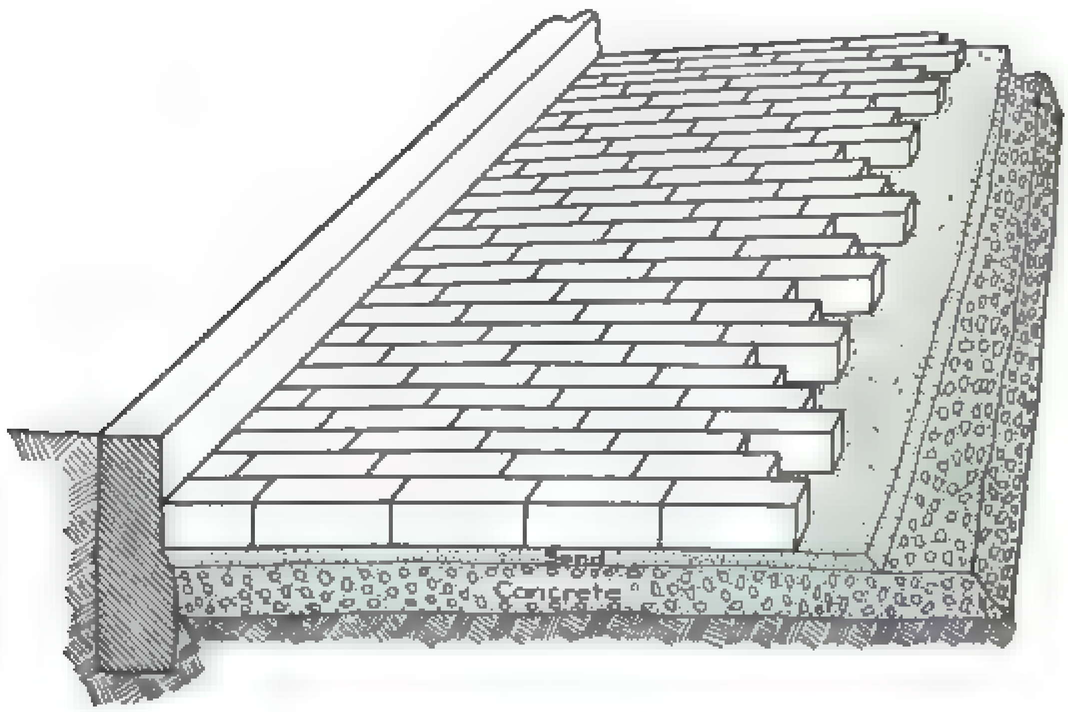

FIG. 130.—SECTION OF BRICK PAVEMENT WITH CONCRETE FOUNDATION.

gravel of proper thickness, when laid as described in § 564, Art. 3, Chapter XII, is sufficient. In some localities the natural soil is so gravelly that it needs only to be leveled and rolled to make a reasonably good foundation, particularly if the traffic is only moderately heavy. Many cities, some of which have a considerable traffic, for example, Cleveland, Ohio, and Galesburg, Illinois, thus lay brick directly upon the native soil. Under certain conditions 4-inch macadam roads have given fair service (see § 321), and a 4-inch course of brick has at least approximately as much stability as an equal thickness of broken stone.

However, it is poor policy to build an inadequate foundation

for a brick pavement. The foundation for any block pavement, whether of brick, stone, or wood, should be substantial enough to keep the blocks in position so that the traffic will be received perpendicular to the face of the block, since then the surface of the pavement will be smoother and the wear upon the blocks will be less. Brick pavements, being made of comparatively small blocks, are proportionally more injured by any derangement of the blocks, and consequently require a very carefully constructed foundation. The best foundation for any particular work will depend upon the character of the soil and the availability of the various materials.

759. During the first ten or fifteen years after the introduction

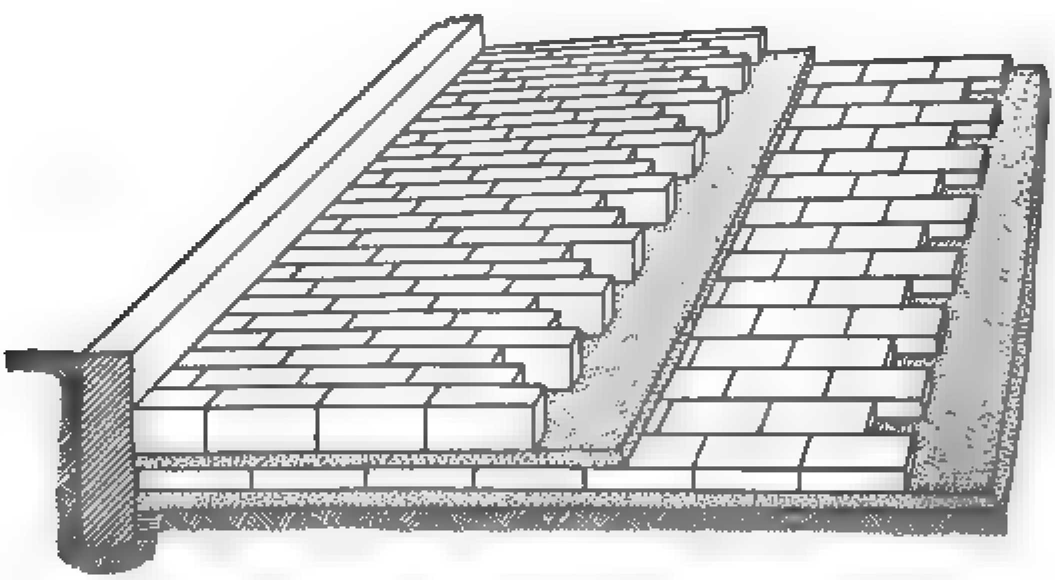

FIG. 131.—SECTION OF BRICK PAVEMENT WITH BRICK FOUNDATION.

of brick pavements in the Middle West, the foundation consisted almost exclusively of a course of brick laid flatwise on a thin bed of gravel or cinders. Fig. 131 is a section of a brick pavement having a brick foundation. Such pavements are generally known as two-course brick pavements. The layer of cinders or gravel was leveled, and inferior paving brick were laid flatwise thereon; and then the joints of the bricks were swept full of sand. Brick foundations were formerly used very extensively, but recently have generally given place either to concrete, crushed stone, or gravel, and are used now only in a few localities which are remote from stone quarries and gravel pits in which brick are

comparatively cheap. The chief defect in this form of foundation was that the joints of the lower course were not fully filled, and consequently after the pavement was in service the sand of the cushion coat (the layer between the two courses of brick) would work into these joints and permit the bricks in the wearing course to settle. To cheapen the pavement, broken and chipped brick were used in the lower course, and the tendency was to place the larger face uppermost, thus making it nearly impossible to fill entirely the joints during the time of construction. This form of foundation was abandoned on account of its cost and inferior quality.

760. The first brick pavement in this country, that at Charleston, W. Va., was laid on a foundation of 1-inch tarred boards resting on a layer of 3 or 4 inches of sand, with a cushion of coat of 1½ inches of sand between the bricks and the boards. This form, known as the Hale or the Charleston foundation, was not used to any considerable extent, and has been entirely abandoned.

761. CUSHION LAYER. This is a layer of sand between the foundation and the wearing course of brick, to secure a uniform bearing for the latter. The proper thickness of this layer will depend upon the regularity of the upper surface of the concrete foundation and also upon the uniformity of the size of the bricks. It should be thick enough to give a uniform support to the bricks, and any greater thickness does no particular harm except that it is a little more difficult to spread exactly uniformly a thick layer than a thin one. In common practice, the thickness varies from ½ to 2½ inches, but usually from 1 to 2 inches. A thickness of 1-inch is enough to fill up all reasonable irregularities of the foundation, but it is not enough to permit a uniform bedding of the brick by rolling. Apparently a 1-inch cushion is not thick enough to permit the sand to flow sufficiently to adjust itself to the inequalities of the brick. Unless the blocks are unusually uniform, the cushion layer should be 2 inches thick.

The thickness should be as uniform as possible, so that the bricks will settle evenly during the rolling; and therefore the top of the concrete foundation should be carefully finished with a surface parallel to the surface of the pavement. Not infrequently loose fragments of stone are left on the surface of the concrete,

a result which is very undesirable, since they necessitate a thicker cushion and at best prevent the bricks from coming to a uniform bearing. With good workmanship in laying the concrete, there will be no loose pieces of stone on the surface ; and if they do happen to get there, they should be removed before laying the cushion coat.

In adjusting the thickness of the sand cushion adjoining a concrete gutter, care should be taken that the upper surface of the brick after being rolled is not below the upper edge of the gutter.

762. When the sand cushion is laid on a foundation of broken stone (§ 562), care must be taken to roll the stone so that the jar of the traffic will not cause the sand to work into the broken stone, thus permitting the pavement to settle and to become rough and uneven. If the broken stone is rolled until the surface of the layer is firm and solid and does not shake under the foot in walking over it, unless the stone is very hard and tough there is not much danger of the sand sifting into the stone.

763. The sand for the cushion should preferably be so fine as to be of a soft, velvety nature. and should contain no pebbles of any considerable size, or loam, or vegetable matter. The size of pebbles permissible depends upon the thickness of the sand bed. Pebbles will prevent the brick from having a uniform bearing; the loam is likely to be washed to the bottom of the layer and cause the brick to settle; while the vegetable matter will decay or wash away, and leave the brick unsupported. The sand should be dry when it is spread. Even a small per cent of moisture in the sand adds considerably to its volume, particularly if it is fine ; and hence if the sand when laid is wet and dry in spots, the cushion will not be of uniform thickness when dry. The shrinkage of the sand cushion away from the brick. under certain conditions causes an unpleasant rumbling of the pavement when heavy vehicles pass over it (see § 781).

764. The spreading of the sand should be carefully done, so as to secure a uniform thickness and to have its upper surface exactly parallel to the top of the finished pavement. After the sand has been distributed approximately to the proper thickness with a shovel, the surface should be leveled by drawing over it a tem-

plate conforming exactly to the curvature of the cross section of the proposed surface of the pavement. Practice differs considerably as to the length of the template.

Some contractors make the template the full width of the pavement, if that is less than about 30 feet, and for a wider pavement make the template half the width of the street. This form of template must be made of a 2-inch pine plank of sufficient width to permit of the cutting of its lower edge to the proper curvature, which may be determined by the method explained in § 310 (page 200). If the template is long, it must be braced to prevent bending and sagging; and it must have a long and substantial handle at each end by which to draw it forward, and another handle at each end by which to carry it backward. It is desirable that the template shall have considerable weight to keep it from lifting up as it is drawn forward; and when being drawn forward, the face of it should lean backward a little to keep it from lifting up. At each end there should be a roller or a metal runner to carry the template along the top of the curb or along the edge of the concrete gutter. If it is to run on top of the curb, a roller also should be provided to keep it away from the curb. If the length of the template is equal to half the width of the street. one end of it may run upon a screed, or wood strip. equal in thickness to that of the cushion layer, placed in the center of the street. If there is a car track in the street, one end of the template may be made to run on the rail.

A long template requires considerable force to draw it forward, some contractors using one or two horses for this purpose, and it is difficult to move backward. Other contractors, therefore, use a template equal to one quarter of the width of the pavement. For a pavement 30 to 40 feet wide, screeds made of 2-inch by 4-inch scantlings are placed at the crown. in the gutters, and also midway between the crown and the gutter, being bedded on a thin layer of sand so that their tops conform to the finished surface of the proposed sand cushion. The position of these screeds is determined by measuring down from a string stretched from curb to curb. The template may be made of a 1-inch by 6-inch plank, with a 1-inch by 2-inch handle braced by two 1-inch by 2-inch pieces. The edge should be hollowed out to fit the curved surface

of the pavement, although often this is not done. The middle ordinate for the curved cutting edge of the template may be computed by the formula $m = \frac{C\,d^2}{D^2}$, in which m is the middle ordinate in inches, C the crown of the pavement in inches, d half the length of the template in feet and D half the width of the pavement in feet.

After the sand for the cushion layer has been distributed with shovels, the template should be drawn slowly over it several times, any depressions that develop being filled by sprinkling sand into them with a shovel. A considerable quantity of sand should be drawn along in front of the template, as this aids materially in packing the bed. It is necessary to draw the template several times to pack the sand well, particularly if there are wet and dry spots, as the successive jarring of the sand grains causes them to settle more closely together. When the sand cushion is properly packed it will have a uniform, smooth, velvety appearance, and will not look rough, porous, and grainy.

765. The surface of the cushion layer is often prepared with a short lute or scraper without any screeds; but the template and screeds secure a more uniform surface and also give a greater compression and a more even bed. With hand luting the surface of the pavement is almost certain to be covered with saucer-like depressions after it has been rolled. Hand luting should be prohibited except where the use of the template is impossible, as around man-hole covers, at street intersections, etc.

A considerable part of the difference in tractive resistance between brick pavements No. 4. and Nos. 5 and 6 of Table 8, page 29, is due chiefly to the difference in the preparation of the sand cushion, the remainder of the difference being in the rolling of the brick (§ 771).

766. LAYING THE BRICK. Delivery. Some contractors pile the brick at the side of the street before commencing the grading, while others haul them to the street and take them directly to the men who lay them. If the brick can be had at the kiln and are shipped exactly when desired, there is a possibility of saving 2½ to 3 cents per square yard by the last method; but there is danger of the street's being kept closed needlessly long owing either to bad wagon roads or to a failure in railroad transportation. The

bricks are hauled over those just placed, planks being laid down to protect the brick; but considerable damage is caused in turning the empty wagons, since the bricks are settled unevenly.

Most contractors use wheel-barrows to deliver the brick to the men who lay them, but a few carry them on a board about 6 inches wide and 24 inches long. The advantages claimed for the last method are that it is cheaper, chips the brick less, and delivers the brick convenient to the setters. The first claim is doubtful, at least with intelligent and efficient laborers; and there is but little danger of chipping good paving brick. When the brick are carried on a board they are delivered convenient to the setters, and there is less likelihood of disturbing the position of the bricks already set; but this method is too expensive to justify its use. The wheel-barrows should never be run on the bare bricks just laid, since it settles them unevenly; but planks should be laid down upon which to run the wheel-barrows. In dumping the barrows, they should be turned to face up or down the street, and then be tipped until the brick slide gently out toward the curb, as otherwise there is a continuous widening of the joints between the courses and a disturbance of the alignment of the rows.

767. Direction of Courses. It is customary to lay the brick with the length perpendicular to the curb, except at street intersections; but there are a few cities in which the brick are laid in courses making an angle of 45 degrees with the length of the street, with the idea that the tendency to form ruts would be less if the wheels crossed the bricks diagonally. There is no advantage in the diagonal over the square courses; they are more difficult to lay, cutting the corner of the brick in making the fit next to the curb is wasteful of material, and the diagonal courses do not give as good foothold to the horses. Occasionally a few courses of brick are laid longitudinally in the gutter, similar to the practice with stone blocks; but this is unnecessary, since the brick pavement is much smoother than the ordinary stone-block pavement, and besides the running joint where the transverse and the longitudinal sections join is likely to develop into a rut.

768. At street intersections and junctions the bricks should be laid diagonally—a compromise position between the directions of the travel on the two streets. Street intersections need special

care in construction, since they are exposed to the traffic of two streets. Fig. 132 shows the usual arrangement of the courses for a street intersection; and Fig. 133 and Fig. 134 (page 504) show two other arrangements that have occasionally been used. Slight objections have been urged against all three plans. The bond in Fig. 132 is weak along the middle line of each street; Fig. 133

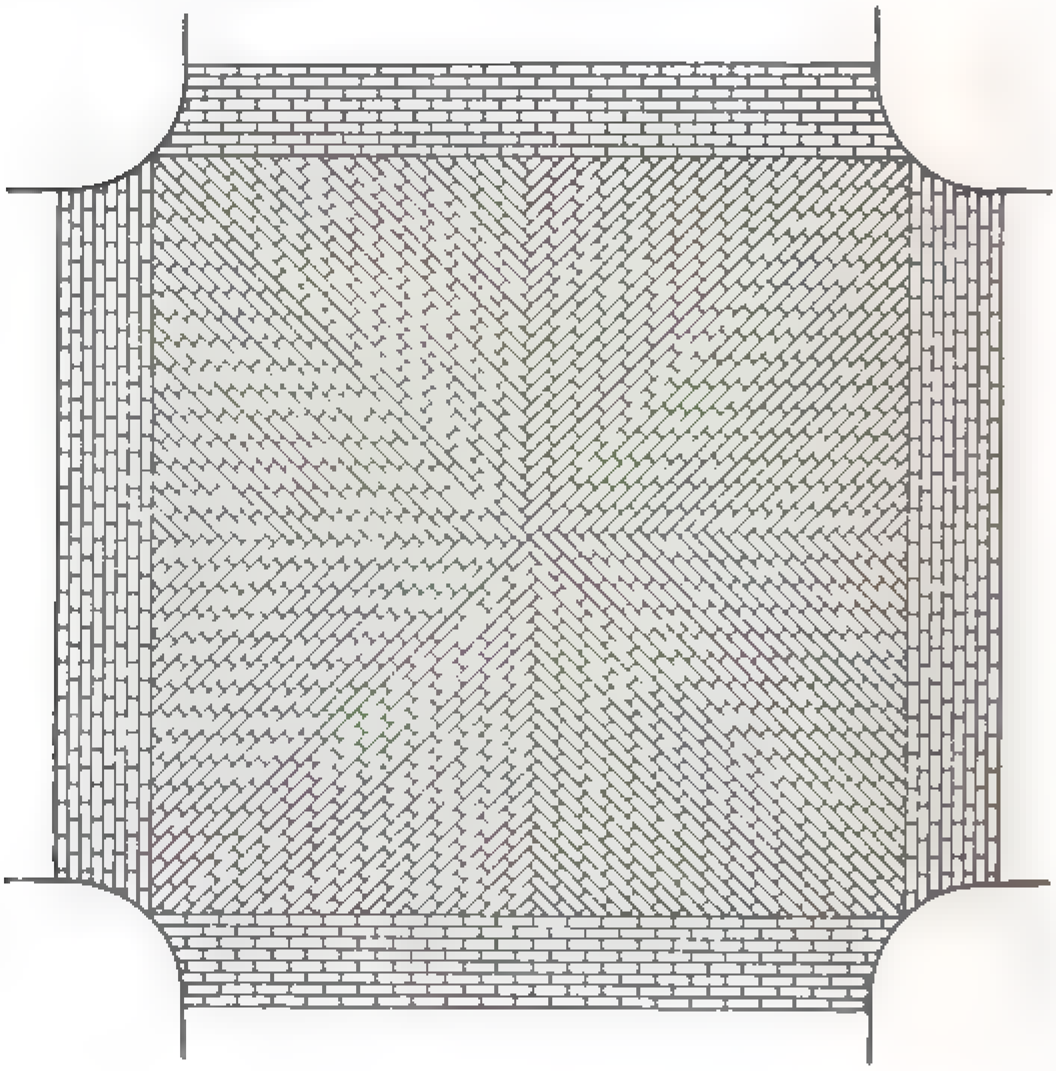

FIG. 132.—DOUBLE-DIAGONAL BRICK INTERSECTION.

is objectionable owing to the tendency of ruts to form along the lines running through the ends of the bricks; and Fig. 134 is defective since traffic around the corners *A* and *B* is parallel to the courses of brick.

At a street junction only half of the common area should be laid with diagonal courses. For example, assuming that in Fig. 132 the street enters the lower side of the transverse street but does not cross it, then the lower half of the intersection would be laid with courses as in the diagram, while in the upper half the

length of the bricks would be perpendicular to the transverse street.

769. Setting the Brick. In setting the brick the man should stand on those already laid, and not upon the sand cushion. Under no consideration should the sand bed be disturbed. The brick should be set on edge as closely and compactly as possible, each being pressed both endwise and sidewise against those already laid. The

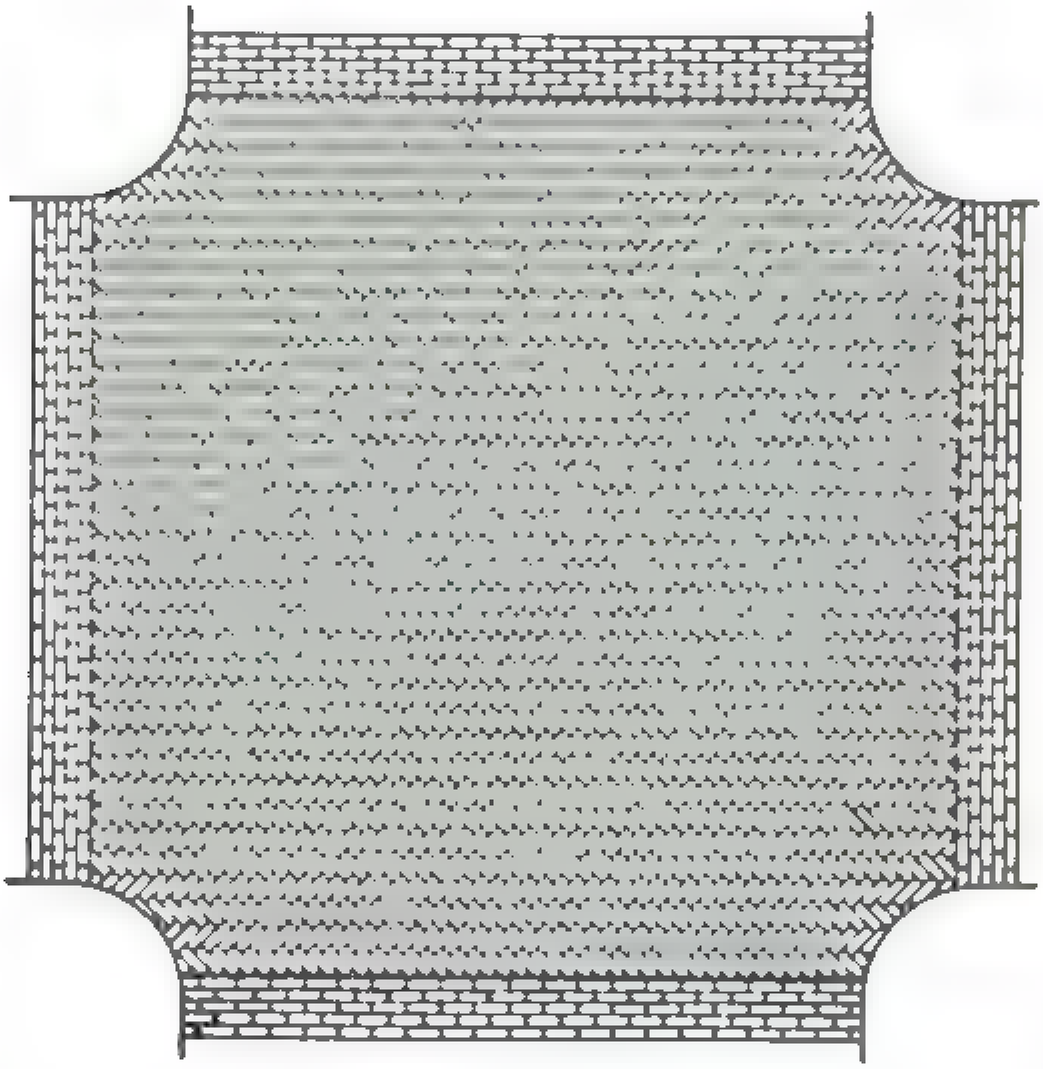

FIG. 181.—HERRING-BONE BRICK INTERSECTION.

bricks are stronger and more durable than any material that can be used to fill the joints, and consequently the thinner the joints the better. The bond should be approximately a half brick. If the brick were laid without bond ruts would be likely to form along the continuous end-joints; and therefore the more the bond the better. No bats should be used, except in making closures; and in cutting a brick to close a course, care should

be taken to get a square end and to make a tight fit. Fig 135 shows the hammer employed in cutting, or rather in breaking, a brick to close a course.

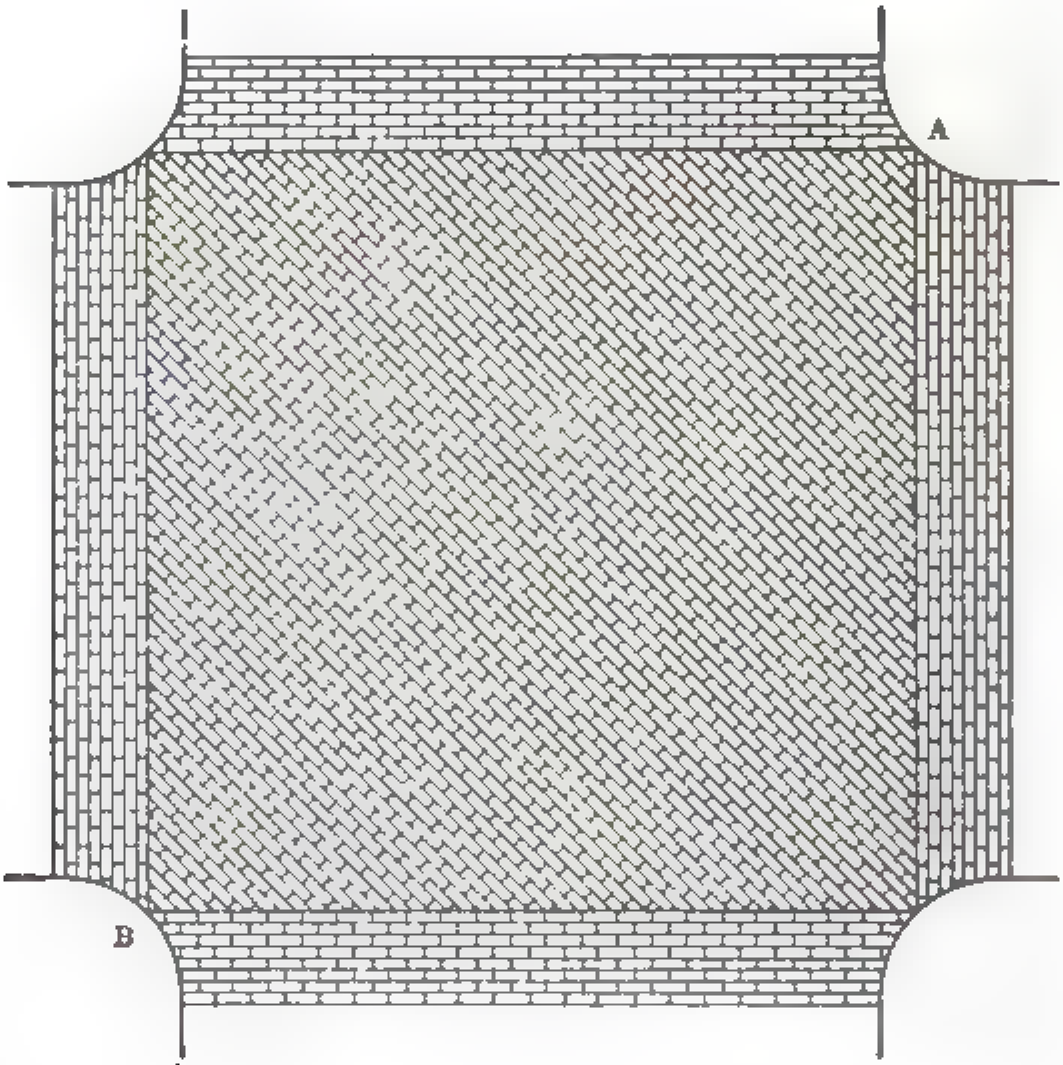

FIG. 134.—SINGLE-DIAGONAL BRICK INTERSECTION.

Some cities specify that the brick shall be gaged to thickness; but this is unnecessary, since even fairly good brick are practically uniform. In some cities it is required that each five or six courses of brick shall be driven up from the face by striking with a sledge against a 2″ × 4″ piece resting against the last course; but this is unnecessary, if each brick when laid is pressed, or rather struck, against the side of the course already in position. In any case the courses should be straight across the street; and if they are not laid so, they should be straightened by

FIG. 135.—BRICK PAVER'S HAMMER.

driving up each five or six courses from the face. Sometimes the bricks in a row are crowded together endwise by inserting a crowbar at the curb; but this is unnecessary provided each brick as it is laid is bumped against the end of the preceding one.

770. Inspecting. After the bricks are laid, the pavement should be inspected, all soft, broken, and badly misshaped brick being marked for removal. To reveal the soft brick, it is customary to sprinkle the pavement heavily with a hose. While the water is being applied, the soft brick will appear comparatively dry; but after the sprinkling is stopped, the soft brick will appear to be the wetter. A brick having only a small piece chipped from the corner or edge may be turned over. Objectionable brick may be marked with chalk, a cross or circle indicating a brick to be removed and a single straight line one to be turned. Rejected brick are removed with tongs having broad flat noses and long stout handles.

771. Rolling. After all rejected brick have been removed and the pavement has been swept, it is ready for rolling, which should be done with a steam roller weighing from 3 to 6 tons. A horse roller is undesirable, since the horse's feet disturb the position of the loose brick, and also since it is impossible to roll the street transversely. The purpose of the rolling is to settle the bricks uniformly into the sand bed, and therefore a steam roller of the asphalt type (Fig. 65, page 225) is better than one of the stone-road type (Fig. 64, page 224). A very heavy roller is undesirable, at least in the beginning of the rolling, since the first passage of it tilts the brick to one side so much that it is nearly impossible to straighten them up again. The roller should not weigh more than six tons, and four tons is better. Unless the top faces of the bricks are brought to a plane, the pavement will be rough and noisy, and will lack durability. The bricks should be firmly settled into the sand bed so that traffic may not depress some of the brick, which will make the pavement rough and also make it wear needlessly fast.

The pavement should first be rolled longitudinally, beginning at the crown and working toward the gutter, taking care that each return trip of the roller covers exactly the same area as the preceding trip so that the second passage of the roller may neutralize any careening of the brick due to the first passage. Pavements

that have been rolled only once or always in one direction, are very much rougher and more noisy than when properly rolled. If a spot is skipped on the return passage of the roller, it can be detected by a casual inspection or by the noise of a passing vehicle. The first passage of the roller should be made at a slow speed, not faster than a slow walk, to prevent undue canting of the brick. After the pavement has been rolled longitudinally, roll it back and forth transversely, or at least in both directions at an angle of 45 degrees from curb to curb.

If the rolling is well done the sand cushion will be pushed up between the brick $\frac{1}{8}$ to $\frac{3}{8}$ of an inch.

772. A comparatively few cities specify that the brick are to be settled into the sand bed by ramming. The weight of the rammer varies from 40 to 90 pounds, usually from 75 to 90 pounds. For the form of rammer ordinarily used, see Fig. 138, page 527. The rammer is used on a 2-inch oak plank laid on the brick parallel to the curb. The proper ramming of a brick pavement is exceedingly hard work, and only a few men are strong enough to do it even fairly well.

Ramming does not tilt the brick; but it costs considerably more, can not give as even a surface, and is not likely to be thoroughly done. A few cities specify that in ramming the surface is to be trued up with a straight edge. An occasional city specifies that the brick shall be first rammed and then rolled with a heavy roller.

In certain places the roller can not be used, as for example next to the curb, or near the edge of a concrete gutter, or around manhole covers, in which cases the pavement must be thoroughly rammed.

773. Filling the Joints. The joints should be filled (1) to keep the brick in the proper position, (2) to lessen the chipping of the edges of the brick, and (3) to prevent water from penetrating to the cushion coat and to the foundation. Three forms of filler are in common use, viz.: sand, tar, and hydraulic cement.

774. *Sand Filler.* Sand was the first filler employed for brick pavements, and in the Middle West is even yet almost exclusively used. The sand should be fine and dry, and be worked into the joints by sweeping it over the pavement, which also should be dry. A few cities specify that the sand shall be heated to dry it, before

being swept into the joints. Although the sand is nominally always swept into the joints, it is usually simply spread upon the surface and left to be worked in by traffic, which is undesirable since the joints are then partially filled with manure and street dirt. The sand can be swept into the joints effectively and economically with a revolving machine sweeper. After the joints have been filled, the surface of the pavement is covered with a layer of sand $\frac{1}{4}$ to $\frac{1}{2}$ inch thick, which is left on for a few weeks after the street is thrown open to traffic, to secure the thorough working down of the sand into every joint. The cost of sweeping the pavement and filling the joints with sand is 0.15 to 0.25 cent per square yard, and the cost of a $\frac{1}{2}$-inch layer of sand at $1.08 per cubic yard is 1.5 cents per square yard. To cover waste and contingencies, the sand joint-filler is usually estimated at 2 cents per square yard.

The advantages of a sand filler are: 1. It is cheap, usually costing about 2 cents per square yard. 2. The pavement may be thrown open to traffic as soon as the bricks are laid. 3. The pavement may be taken up easily and without breakage of the brick. 4. It is practically water tight, particularly after being in service a short time. Whenever a brick pavement having a sand filler is opened, the sides of the brick are always found dry and clean a little distance below the wearing surface.

The disadvantages of a sand filler are: 1. It does not protect the edges of the brick from chipping. 2. It may be washed out on steep slopes. 3. It is removed from the top of the joints by the street sweeper—either the broom or the pneumatic.

775. *Tar Filler.* A No. 5 or No. 6 coal-tar distillate (§ 698) is often used as an interstitial filler for brick pavements. The bricks should be dry, and the tar should be applied at a temperature of 300° to 320° Fahr. by being poured into the joints with a vessel very much like a sprinkling pot without the rose. The success or failure of the tar filling depends on the efficiency and care of the person in charge of heating the tar. If the tar be too hard, it pulverizes in very cold weather; if it be too soft, it runs and becomes sticky in very hot weather.

The cost depends upon the locality and the closeness of the joints. Usually tar costs from 6 to 8 cents a gallon; and one gallon is generally sufficient for one square yard of pavement. The

total cost of the filler varies from 10 to 12 cents per square yard of pavement.

Tar is superior to sand in that it makes a perfectly water-tight joint; and it is superior to hydraulic-cement grout in that it is not so rigid and therefore makes a more quiet pavement. Tar costs more than sand, and does not protect the edges of the brick as well as hydraulic-cement grout.

The objections to tar are: 1. In summer it is likely to melt and run out of the joints; and in winter it is brittle and likely to chip out of the joints. 2. The heating of it makes unpleasant odors on the street.

776. Sometimes asphalt is mixed with the tar to make it less susceptible to changes of temperature, and sometimes asphalt is substituted for the tar. Unfortunately a mixture of tar and asphalt is often referred to as tar and also as asphalt, and frequently as pitch—a term also applied to tar or asphalt;—and consequently it is difficult to determine the practice in different cities. A common composition of "asphalt" filler is: refined asphalt, 20 parts, residuum oil, 3 parts; and coal-tar distillate No. 4, 100 parts. It is not clear that using a thicker tar and entirely omitting the asphalt and the residuum oil would not give an equally good filler. The different asphalt paving companies sell an asphalt paving filler.

777. *Cement Filler.* The most common joint filler, other than sand, is a thin mortar composed either of neat Portland cement or of 1 part cement and 1 part fine sand, the latter proportions being the more common. The pavement should be copiously sprinkled immediately before the grout is applied. The sand and cement should be mixed in batches, say, of not more than 40 or 50 pounds of each at one time, in a tight mortar box. The box for this purpose should be 3½ to 4 feet long, 27 to 30 inches wide, and 14 inches deep, and should have legs of different lengths, so that the mixture will readily flow to the lower edge of the box, which should be 8 to 10 inches above the pavement

The sand and the cement should first be mixed dry, and when the dry mixture assumes an even and unbroken shade, water should be added in a sufficient quantity to form a grout of the consistency of thin cream. The grout should be removed from the box to the pavement with a scoop shovel, and not by overturning the box

upon the pavement; since by the last process the sand, cement, and water are separated, and are deposited in different portions of the pavement. While the box is being emptied, the grout should be constantly stirred to prevent a separation of the sand from the cement; and after the grout has been applied to the pavement, it should be quickly swept into the joints with steel brooms. It is better that the joints should be only about half filled at the first application, since then there is a less depth of grout in the joints and consequently less liability of the separation of the sand, the cement, and the water.

To secure the best results, a mortar box should be provided for each 10 feet of width of street, and the full width of the street should be filled at practically the same time. After the filling has been carried forward for 40 or 50 feet, the same space should be filled again in like manner, except that the mixture for the second filling should be slightly thicker than the first. The joints should be filled entirely to the top in the second application. After the joints have thus been filled, a half inch of fine sand should be spread over the entire surface of the pavement; and if the weather is very hot or dry, the sand should be sprinkled at intervals for two or three days, to insure that the cement does not lose by vaporization the water necessary for chemical combination in setting. Traffic should be kept off the pavement from seven to ten days, or at least until the cement has firmly set. If the cement filler is disturbed before it is fully set, it is practically no better than sand. If the cement filler is put in as described above and allowed to set firmly before being used, it will wear no faster than the best paving blocks and will prevent spalling and chipping of the bricks at the edges and corners.

778. The amount of grout required will vary with the openness of the joints, with the depth of the grooves (§ 728), and also with the quantity of sand of the cushion coat that works up into the lower part of the joints while the bricks are being rolled. With a 2-inch cushion and thorough rolling with a 5-ton roller, the sand will be forced up from $\frac{1}{4}$ to $\frac{1}{2}$ inch. With a grout mixed 1 to 1, a barrel of cement will fill from 25 to 40 square yards; and with a grout composed of 1 part cement and $1\frac{1}{2}$ of sand, a barrel will fill from 40 to 60 square yards.

If the grout is mixed in large quantities and dumped upon the pavement, it will require about one hour of labor for each 25 square yards. The cost of labor in applying the grout in small quantities as described in § 777 varies from 1 to 1.25 cents per square yard. The cost of the cement filler will depend upon the price of cement and the care employed in applying the grout. With ordinary re-pressed blocks and reasonable care in securing close joints, the cost of a 1 to 1 Portland-cement grout will usually vary from 8 to 12 cents per square yard. If the grout is dumped from the box upon the pavement, the cost will probably be from 8 to 10 cents per square yard; but if it is mixed in small quantities and applied as described in the first paragraph of § 777, the cost will probably be 10 to 12 cents.

779. The advantage of the cement filler is that it protects the edges of the bricks from chipping, and thus adds to the durability of the pavement. When the joints are filled with sand or tar, the edges of the brick chip off, the upper faces wear round, the pavement becomes rough, and the impact of the wheels in jolting over the surface tends to destroy the brick; while with a good cement filler, the edges do not chip, the whole surface of the pavement is a smooth mosaic over which the wheels roll without jolt or jar, and consequently the life of the pavement is materially increased.

An objection to the cement filler is that it does not take up the expansion of the pavement due to increase of temperature, and that consequently the pavement is likely to rise from the foundation and give out a rumbling noise as vehicles go over it. This rumbling can be eliminated by inserting special expansion joints as described in § 786.

Another objection to the cement filler is that in making repairs it is difficult to remove the brick without breaking many, and it is difficult to clean the brick so that they may be used again. This is an advantage, if it will in any degree prevent the tearing up of the pavement; and at best this objection ought not to have much weight against durable construction.

A third objection is that the street can not be used while the cement is setting. Often the cement is not allowed to set fully before throwing the street open to traffic, and consequently the chief advantage of the rigid filler is lost.

780. *Patent Fillers.* There are a number of joint-filling compounds upon the market whose composition either is a secret or is protected by a patent. The chief components of some of these seem to be tar or asphalt, or a mixture of the two; while others seem to be composed largely of hydraulic cement. It has not been proved that any of these compounds are either better or cheaper than Portland-cement grout.

781. RUMBLING. If all the joints of a brick pavement are filled with cement grout, vehicles in going over the pavement are likely to produce a considerable rumble or roar, due apparently to a hollow space between the bricks and the foundation. At times this rumbling is very pronounced. It is most common in hot weather, but occurs also in cold weather. The fact of this noise and its remedy are more clearly established than its cause. The hollow space under the pavement which gives rise to the rumbling may be due to any one of three distinct causes, viz.: 1, expansion of the pavement due to an increase of temperature; 2, crowding inward of the curbs due to expansive action of the freezing water in the soil outside of the curbs; and 3, shrinkage of the sand cushion due to its drying out.

782. In hot weather, the crown of the pavement may be lifted from the foundation by the expansion of the bricks due to an increase of temperature. This can occur only when the curbs are firmly enough supported to serve as the abutments of the layer of brick when acting as an arch. To this explanation it has been objected (*a*) that the expansion of the brick would be insufficient to produce the effect and (*b*) that the single course of brick could not act as an arch and carry a loaded vehicle.

The amount and force of expansion of a brick pavement having cement-filled joints is illustrated by the fact that not infrequently the thrust of the pavement is sufficient to force the curb outward except where it is supported by the walk from the curb to the adjoining property, at which places the break in the curb makes manifest its movement. Again, in pavements having all of the joints filled with cement, a considerable number of joints, both transverse and longitudinal, can be found in which the cement mortar has been crushed until it is practically only so much sand. Further, the expansion of the top course of brick is frequently

sufficient to lift the brick from the foundation and form a ridge in the surface. This ridge sometimes runs crosswise of the street and sometimes lengthwise, according to whether it is due to longitudinal or to transverse expansion. If the ridge is only an inch or two high, the pavement will be likely to settle gradually nearly or quite back to its former position, without material damage; but occasionally the ridge rises to a height of a foot or more, in which case a crack usually opens at the highest point and finally a considerable strip of the pavement breaks up, some of the bricks not infrequently being thrown several feet into the air.

What will be the effect of a difference of temperature of 30° F. on a brick pavement 40 feet wide having a crown of 6 inches? The co-efficient of expansion of brick is 0.000,003,4 for 1° F.,* and 40 feet for a difference of temperature of 30° F. would be 0.000,003,4 $\times$ 30 $\times$ 40 $\times$ 12 = 0.049 inch. If the pavement lifts from its foundation and acts as an arch, its own weight will compress the bricks and in part neutralize the expansion. Owing to the lack of the necessary data the amount of this compression can not be computed accurately. The pavement if 4 inches thick will weigh about 45 pounds per square foot. The co-efficient of elasticity of ordinary brick is about 3,500,000 pounds per square inch,† and of paving brick from 3,500,000 to 7,000,000 pounds per square inch;‡ the co-efficient of elasticity of ordinary Portland cement mortar is about 1,500,000 pounds per square inch.§ It will be assumed that the co-efficient of elasticity of a brick pavement is 4,000,000 pounds per square inch, which is exact enough for the purpose of this illustration. Considering a strip of the pavement 1 foot wide and equating the moment of the crown thrust and the moment of the weight of half the pavement, we find that the compression in the arch is approximately 18,000 pounds. If the thrust is uniformly distributed it is equal to a compression of practically 400 pounds per square inch, and will produce a shortening of 0.048 inch in

* Annual Report on Tests of Metals and Other Materials—report of tests made with the U. S. government testing machine at the Watertown (Mass.) Arsenal,—1896, p. 367-69 The result quoted is the mean of seventeen.

† Baker's Masonry Construction, 9th edition, p. 14

‡ Annual Report on Tests of Metals and Other Materials, 1896, p. 348, 353, 358, 359, 362, 364.

§ Baker's Masonry Construction, 9th edition, p. 14.

the width of the pavement. This shortening is almost exactly the expansion for a change of 30° F., and consequently a rise of temperature of 30° would be required to neutralize the compression of the brick due to the arch action of the pavement, and any conditional increase of temperature would lift the brick from the foundation.

Assuming the cross section of the surface of the pavement to be an arc of a circle, its radius is approximately 400 ft. The difference in length between the arc and the chord can be computed with sufficient accuracy by the following well-known formula:

$$a - c = \frac{c^3}{24 r^2}$$

in which a equals the length of the arc, c equals the length of the chord (the width of the street), and r equals the radius of curvature of the arc. In the above example, the length of the arc is 0.192 inch greater than the width of the street. The rise at the crown is practically proportional to the difference in length between the arc and its chord. The expansion for 20° F. is $0.000,003,4 \times 20 \times 40 \times 12 = 0.032,6$ inch, which is practically one sixth of the difference between the normal length of the arc and the chord of a 40-foot pavement having a 6-inch crown. Therefore an increase of temperature of 20° above the 30° considered in the preceding paragraph, *i. e.*, a total rise of 50° F., will lift the crown of the pavement approximately 1 inch from the foundation, provided the curbs are immovable.

Of course, the preceding investigation is only approximate, but it shows the possibility of a pavement's being lifted from its foundation through the action of heat. Whether or not the pavement will be lifted from the foundation will depend upon (1) the solidity of the curbs, (2) the rigidity of the filler, (3) the thickness of the joints, (4) the temperature of the pavement when the joints were filled, (5) the maximum temperature, and (6) the duration of the high temperature.

If the bricks lift from the foundation, why does not the very flat arch thus formed break down when a heavy vehicle comes upon it? The bricks of the pavement are firmly cemented together, and the whole acts somewhat as a bent beam, and there is

so much flexibility in this brick beam that it deflects and touches the foundation at points sufficient to prevent the destruction of the arch, and still is unsupported at enough points to give out a rumbling sound.

783. In cold weather, the pavement may be lifted from its foundation by the freezing of the water in the earth outside of the curbs forcing the curbs inward. It is well known that water in freezing expands with considerable force; and if each curb of a 40-foot pavement is forced inward 1 of an inch, the crown of the pavement will be lifted more than an inch from the foundation. This result will occur only when the subsoil outside of the curbs freezes while it is at least nearly saturated with water.

It is claimed that the lifting of a brick pavement in cold weather is due to the freezing of the water absorbed by the brick. In support of this view it is claimed that pavements made of brick having a high absorptive power more frequently give out a rumbling sound than those made of brick having a low absorptive power. The theory hardly seems plausible, since at best the per cent of water absorbed is very small and its expansion would be taken up to a considerable extent by the air remaining in the pores of the brick. The facts offered in support of the above theory doubtless have some other interpretation.

784. Sometimes spots only a few feet in diameter give out a rumbling sound; and on account of the limited area of these spots, the rumbling can not be due to either of the causes discussed above. These spots are probably due to a shrinkage of the sand cushion by its drying out. A small per cent of water adds considerably to the volume of fine sand, and hence if the sand cushion is wet when laid and dries out after the cement filler has set, the brick will be left unsupported. These spots disappear with the use of the pavement—probably by the breaking of the cement and the settling of the bricks.

785. It is claimed that the rumbling is due to the shrinkage of the concrete; but this can not be correct as the bricks are not laid until the concrete is firmly set.

It is also claimed that the rumbling is due to large pebbles in a thin sand cushion, which keep the bricks from obtaining a firm bed in the sand; but this is at least doubtful, since such pebbles

would probably be crushed during the rolling, and besides many such pebbles would be required to produce the observed noise.

786. Expansion Cushions. The rumbling of the pavement (§ 781) can be prevented by placing a tar-joint from ½ to 1 inch thick next to each curb. The compression of the tar allows the bricks to expand without lifting the pavement from its foundation. This tar-joint can be inserted by setting a 1-inch board next to the curb before laying the bricks, and then after the bricks are laid withdrawing it and filling the space with coal-tar distillate No. 5 or 6.

The longitudinal expansion can be taken up either by filling three or four transverse joints with tar, each 25 or 30 feet, or by inserting a 1-inch tar-joint each 40 or 50 feet.

787. In one case a 1-inch expansion joint at each curb and two transverse tar-joints every 50 feet required one barrel (50 gallons) of tar for each 274 square yards of a pavement 36 feet between curbs, or say 1 gallon of tar for each 5 or 6 square yards of pavement. In another case, a ½-inch expansion joint at each curb and a ½-inch transverse expansion joint at each 35 feet required 237 gallons of tar for 2,870 square yards of pavement or 1 gallon for each 12 square yards.

788. PERMISSIBLE GRADES. Table 50 shows the steepest grades of brick pavement in actual use in 1900 in the cities named.

TABLE 50.

MAXIMUM GRADES OF BRICK PAVEMENTS.

CITY.	STATE.	GRADE.
Albany	New York	9.3 per cent
Baltimore	Maryland	15 " "
Columbus	Ohio	9 " "
Des Moines	Iowa	11 " "
Erie	Pennsylvania	7 " "
Joliet	Illinois	6 " "
Mansfield	Ohio	8 " "
Milwaukee	Wisconsin	8 " "
Nashville	Tennessee	7 " "
Parkersburg	West Virginia	15 " "
Peoria	Illinois	8.4 " "
Philadelphia	Pennsylvania	6 " "
St. Joseph	Missouri	10 " "
Toledo	Ohio	5.6 " "
Troy	New York	7 " "
Wheeling	West Virginia	8 " "

"The fact that such steep grades are in use, may not be taken as a reason for imitation, but may furnish conclusive reasons for avoidance. The most useful information on the subject can be obtained from teamsters and horsemen of these cities. If it is generally agreed that certain pavements are shunned by teamsters because their horses slip and fall when going down a certain street with a load, it will evidently be unwise to repeat the construction of the same kind of pavement with an equal slope in a similar climate. An examination of these pavements may furnish to the observer conclusive reasons for or against copying them, or may suggest changes in detail which would give better results. In investigating these steep grades, it should be borne in mind that the selection of the pavement for a given street may have been made directly or indirectly by the property owners, who have not necessarily chosen the pavement best suited to attract traffic, but who, preferring a quiet street, sometimes select a pavement which traffic will shun." *

789. Merits of Brick Pavements. Bricks as a paving material have some attractive features. 1. They may be had in small units of practically uniform size. 2. They may be had in large or small quantities. 3. They may be laid rapidly without special expert labor. 4. When ailing pipes or other causes necessitate the disturbance of the pavement, ordinary tools and intelligence can restore the original surface. 5. Brick pavements give a good foothold for horses. 6. They do not wear slippery. 7. They are adapted to all grades. 8. They have low tractive resistance, particularly if the joints are filled with Portland cement grout. 9. They are not specially noisy when properly laid. 10. Brick pavements yield little mud or dust. 11. They are easily cleaned. 12. If the joints are filled with sand, they are only slightly absorbent; and if filled with tar or cement, they are non-absorbent. 13. Brick pavements have a pleasing appearance. 14. They are very durable, particularly if the joints are filled with Portland cement. 15. They are easily repaired.

790. Cost of Brick Pavements. The cost will vary with the locality and the details of construction, and consequently any

* City Roads and Pavements, by William P. Judson. Second Edition. 193 p. 4"×6." Published by the author, New York City, 1902.

general statement of cost will be only approximately true for any particular case.

The grading is usually done by the cubic yard; and the cost varies with the character of the soil, the depth to be removed, the length of haul, etc. The cost of grading ranges from 15 to 50 cents per cubic yard; but in easy soil and moderate cuts, it generally varies from 20 to 30 cents. It usually costs 2½ to 3 cents a square yard to dress off the subgrade after it has been graded with drag or wheel scrapers, and to throw the material into wagons.

The cost of rolling the subgrade will depend upon whether it is rolled longitudinally only or both longitudinally and transversely. With a horse roller the cost of labor in rolling the street longitudinally will probably not be more than 0.1 to 0.15 cent per square yard; but the cost on account of interest on the value of the roller will depend upon the amount of work done per year, and may be from ½ to 1 cent per square yard. With a steam roller the cost of rolling, both transversely and longitudinally, will be about 0.5 cent a square yard, exclusive of interest, storage, and depreciation of the roller.

The cost of the concrete will vary with the price of cement, the proximity of broken stone or gravel, the character of the concrete, etc. Ordinarily the materials for a 6-inch course will cost about 40 cents per square yard (§ 559), and the labor 6 to 8 cents per square yard (§ 560).

The price of brick varies greatly with the locality, particularly with the freight rate. The price of bricks or blocks is usually quoted by the thousand without stating the size or number required to lay a square yard. For convenience in making estimates and comparisons, Tables 51 and 52 are given, to show the number required per square yard. The first table gives the quantities for the foundation course, and the second for the top course. In Table 52, the upper number in each entry is for ⅛-inch joints, which is perhaps a little close for re-pressed blocks; and the lower number is for ¼-inch joints, which is probably a little too open for a block not re-pressed. The price of *bricks* per thousand at the kiln varies from $7.00 to $15.00, but usually from $8.00 to $10.00; and assuming the size to be 2½″ × 4″ × 8½″, of which 54 not re-pressed are required to lay a square yard of pavement,

TABLE 51.

NUMBER OF BRICKS REQUIRED FOR ONE SQUARE YARD OF FOUNDATION COURSE.

Brick Laid Flatwise with ¼-inch Joints.

Length of Brick, in Inches.	Width of Brick, in Inches.									
	3½	3⅝	3¾	3⅞	4	4⅛	4¼	4⅜	4½	5
7¾	43.2	41.8	40.5	39.3	38.1	37.0	36.0	35.1	34.1	30.9
7⅞	42.5	41.2	39.9	38.7	37.6	36.4	35.4	34.6	33.6	30.4
8	42.0	40.5	39.3	38.1	36.9	35.9	34.9	34.0	33.1	29.9
8⅛	41.3	39.9	38.7	37.6	36.4	35.3	34.4	33.5	32.6	29.5
8¼	40.6	39.3	38.1	37.0	35.9	34.8	33.9	33.0	32.1	29.1
8⅜	40.1	38.7	37.6	36.5	35.4	34.3	33.4	32.6	31.6	28.6
8½	39.5	38.2	37.0	36.0	34.8	33.8	32.9	32.1	31.1	28.2
8⅝	38.9	37.7	36.5	35.4	34.4	33.3	32.5	31.6	30.7	27.8
8¾	38.4	37.1	36.0	35.0	33.9	32.9	32.0	31.1	30.3	27.4
8⅞	37.9	36.6	35.5	34.5	33.4	32.5	31.5	30.7	29.9	27.1
9	37.3	36.1	35.1	34.0	33.0	32.0	31.1	30.3	29.5	26 7
10	33.8	34.1	31.6	30.7	29.7	28.9	28.1	27.4	26.6	24.1

the cost will usually vary from 43 to 54 cents a square yard exclusive of freight. The price of re-pressed *blocks* at the kiln varies from $12.00 to $14.00 a thousand; and assuming the size to be 3″ × 4″ × 9″ of which 46 are required to lay a square yard (see Table 52), the cost of the blocks exclusive of freight will usually vary from 55 to 65 cents a square yard. In estimating the freight, it may be helpful to know that a brick 2″ × 4″ × 8″ will weigh about 5 pounds, and one 2½″ × 4″ × 8½″ about 7 pounds, and a block 3″ × 4″ × 9″ about 9 pounds. In estimating freight, the fact should not be overlooked that for one reason or another a considerable number of bricks are rejected. With careful grading at the kiln the broken and rejected brick is likely to be 2 to 4 per cent.

The cost of hauling and piling on the side of the street is about

TABLE 52.

NUMBER OF BRICKS REQUIRED FOR ONE SQUARE YARD OF TOP COURSE.

The upper number in each case is for ⅛-inch joints, and the lower for ¼-inch joints.

Length of Brick, in Inches.	Thickness of Brick, in Inches.										
	1⅞	2	2⅛	2¼	2⅜	2½	2⅝	2¾	2⅞	3	4
7¾	82.1 76.2	77.6 72.0	73.2 68.0	69.3 64.8	65.8 61.8	62.8 58.9	59.7 56.4	57.5 54.0	54.9 52.0	52.7 49.8	39.9 38.1
7⅞	81.1 75.3	76.2 70.8	72.0 67.2	68.0 63.9	64.8 60.8	61.8 58.1	58.9 55.4	56.4 53.1	54.0 51.1	52.0 49.1	39.3 37.6
8	80.1 74.1	75.3 69.8	70.8 66.1	67.2 62.9	63.9 60.0	60.8 57.0	58.1 54.4	55.4 52.5	53.1 50.8	51.1 48.4	38.7 36.9
8⅛	78.5 72.8	74.1 58.9	69.8 65.1	66.1 62.0	62.9 59.2	60.0 56.4	57.1 53.8	54.4 51.6	52.5 49.7	50.4 47.7	38.1 36.4
8¼	77.1 72.0	72.8 67.9	58.9 64.2	65.1 61.1	62.0 58.1	59.2 55.5	56.4 52.9	53.8 50.8	51.6 48.9	49.7 47.0	37.6 35.9
8⅜	76.2 70.8	72.0 66.8	67.9 63.2	64.2 60.0	61.1 57.4	58.1 54.7	55.5 52.3	52.9 50.0	50.8 48.2	48.9 46.3	37.0 35.3
8½	75.4 69.7	70.8 65.8	66.8 62.3	63.2 59.2	60.0 56.6	57.4 53.8	54.7 51.4	52.3 49.3	50.0 47.5	48.2 45.7	36.5 34.8
8⅝	74.1 68.9	69.7 64.8	65.8 61.4	62.3 58.4	59.2 55.9	56.6 53.1	53.8 50.6	51.4 48.7	49.3 46.8	47.5 45.1	36.0 34.4
8¾	73.2 67.9	68.9 63.8	64.9 60.6	61.4 57.6	58.4 54.9	55.9 52.5	53.1 50.0	50.0 48.0	48.7 46.1	46.8 44.4	35.4 34.0
8⅞	72.0 67.1	67.9 63.2	63.8 59.7	60.6 56.8	57.6 54.2	54.9 51.6	52.5 49.3	50.8 47.3	48.0 45.5	46.0 43.7	35.0 33.4
9	71.2 66.1	67.1 62.3	63.2 58.9	59.7 56.1	56.8 53.6	54.2 51.0	51.6 48.7	49.3 46.8	47.2 44.9	45.5 43.1	34.5 33.0
10	64.1 59.7	60.3 56.1	58.6 52.9	53.8 50.6	51.2 48.3	48.9 45.9	46.6 44.1	44.5 42.2	42.6 40.5	41.0 38.9	31.1 29.7

$1.00 per thousand for a haul of 1 mile, of which sum about half is the cost of loading and unloading and half the cost of team and driver; but this cost for team and driver necessitates the use of three wagons with each team.

The number of bricks that a man can set in a day varies with the size of the bricks or the blocks. An average laborer, exclusive of preparing the surface, can set 10,000 to 12,000 small brick in 10 hours; and an expert will set 15,000 in 10 hours. "Under unfavorable circumstances nine men in 13 hours prepared the sand bed, set the brick, and completed the pavement at the rate of 3,160 bricks per hour per man." * An ordinary laborer can set 8,000 or 10,000 3" × 4" × 9" blocks in 10 hours, and a good man will set 10,000 to 12,000.

The organization of a paving gang is usually about as follows:

1 man in charge of spreading the sand cushion	$2.50
1 helper on the sand cushion	1.50
6 men wheeling blocks from wagons	9.00
4 men setting blocks	10.00
1 man sweeping pavement and filling joints with sand	1.50
Total per day of 10 hours	$24.50

This gang should lay at least 1,000 square yards in 10 hours, and under very favorable conditions should lay 1,200 square yards. The cost then of laying, including preparing the sand bed, setting the blocks, and filling the joints with sand, and including also general superintendence, is from 2¾ to 3½ cents per square yard. If the brick blocks are piled upon the side of the street, one and possibly two more men will be required to deliver the blocks, depending upon the height and condition of the surface upon which the bricks are piled; and the cost of laying will therefore be increased 2 or 3 cents per square yard. Not infrequently the total cost of laying the brick is 8 or 9 cents per square yard; but this excessive cost is due to poor management.

In a particular case, 80 hours were required to turn the chipped blocks and to replace the rejected blocks with good ones, in 1,633 square yards of pavement, or, say, 1 hour for each 20 square yards. The blocks were 3" × 4" × 9", and about 2 per cent were turned and about 2 per cent were rejected.

The cost of filling the joints of a brick pavement is about as follows: with sand, 2 cents per square yard (§ 774); with tar, 10 to

* Municipal Engineering, Vol. 3, p. 129.

12 cents (§ 775), and with Portland-cement grout mixed in small quantities and dipped upon the pavement, 10 to 12 cents per square yard (§ 777), and with uniform brick and care in getting thin joints may be only 9 or 10 cents.

The expansion joints will require a gallon of tar for each 5 or 6 square yards of pavement at a cost of, say, 8 cents per gallon, or 1½ cent per square yard of pavement.

A summary of the preceding data on the cost of brick pavements is as follows:

Items.	Cost per Sq. Yd.
Subgrade: rolling	$0.002
Concrete, 6 inches: materials (see § 790)	.40
labor laying	.07
Sand cushion: 2 inches of sand at 90 cents per cu. yd	.05
labor spreading	.005
Brick blocks, 4 inches deep: f. o. b. cars at destination	.60
hauling to the street	.04
setting	.03
rolling	.003
turning and removing	.01
Filling joints with sand and top dressing	.02
Total, exclusive of administration, tools, profits, etc	$1.27

If the joints are to be filled with Portland-cement grout 1 to 1 in the best manner (see § 777), add 10 cents per square yard to the above for the grout filling, and 1½ cents per square yard for the expansion joints.

791. The average cost of 17,000 square yards of brick pavement constructed by the City of Minneapolis, Minn., in 1897 by the city's force is given below.* The foundation consisted of 6 inches of concrete composed of 1 part natural cement, 2 parts sand, and 5 parts broken stone. The sand cushion was 1 inch thick. The bricks were re-pressed, and were made in Galesburg, Ill. They were 2½" × 4" × 8", and cost $15.54 per thousand, or 87 cents per square yard, f. o. b. cars Minneapolis. The joints were filled with a patent filler, under contract with the patentee. Half-inch expansion joints were inserted across the street about 150 feet

* Jour. Assoc. of Engineering Societies, Vol. 20, p. 235–38.

apart. The wages of common labor were $1.75 per day, and of pavers $2.00. Teams received $3.50 per day.

ITEMS.	COST PER SQ. YD.
Removing old pavement	$0.035
Grading	0.032
Concrete	0.467
Planking concrete, lumber, and miscellaneous	0.008
Brick	0.870
Hauling	0.038
Sand cushion	0.018
Laying brick	0.032
Murphy joint filler	0.175
Total	$1.675

792. The cost of brick pavements vary greatly with the locality, chiefly owing to the difference in the cost of transportation; but in the states of Ohio, Indiana, Illinois, and Iowa, and the nearby portions of the adjoining states, the cost of a pavement composed of re-pressed bricks or blocks on a 6-inch concrete foundation generally ranges from $1.20 to $1.70 per square yard.* If no concrete is required for a foundation, the above prices may be reduced 48 or 55 cents per square yard.

ART. 3. MAINTENANCE.

793. The maintenance of a brick pavement consists in watching it, especially during the first year or two, to see that no depressions occur due to insufficient foundation or to the use of defective brick. Any low place due either to the settling of the foundation or to the wear of a soft brick, is rapidly increased both in depth and in area by the impact of the wheels in dropping into the hole. When any unevenness of surface from either of these causes appears, it should be at once rectified before the pavement wears unevenly.

Brick pavements that have been constructed of good material and have been kept in good surface during their early use,

* For the cost of brick paving in eighty-one cities during the years 1895–97, see Proc. Amer. Soc. Municipal Improvements, Vol. 4, p. 138. The above were years of great industrial depression, and hence the data are not of much value.

wear down uniformly and keep smooth with practically no expense for repairs. A striking example of this is seen in Terre Haute, Ind., a city having a population in 1900 of 36,673, where a brick pavement having a concrete base and cement-filled joints, on the principal business street, after eleven years of wear without any repairs, is nearly as smooth as a marble mosaic. The top faces of the brick are flat, and the joints are level full of cement grout. Scarcely a single chipped or broken brick can be found; and the general wear in the middle third of the street has been only about $\frac{1}{64}$ to $\frac{1}{32}$ of an inch of depth, with a very few holes $\frac{1}{8}$ inch deep caused by soft brick. Other pavements of several other lots of brick that have been in service a shorter time are proportionally as durable. The brick are probably not as good as those made at the present time; but the pavement, particularly for that time, was unusually well constructed. It was provided with an adequate foundation, the brick were well burned, and were carefully and thoroughly rolled, and the joints were entirely filled with good Portland-cement grout, and consequently this pavement has worn exceedingly well. Of course other pavements constructed with as good material and with the same care would wear equally well.

794. GUARANTEE. Only a comparatively few cities require a guarantee of brick pavements (see § 450). Below are the specifications employed by the City of Buffalo, N. Y., to determine whether or not the pavement shall be repaired. A few other cities use a somewhat similar, but less severe, specification.

"During the period of maintenance, whenever the surface becomes uneven, holding water more than one eighth inch in depth, or when the pavement has settled over trenches, or heaved, showing a variation of more than three eighths inch from the line of a 4-foot straight edge, the brick shall be then taken up and be re-laid at proper crown and grade. If in any continuous 300 lineal feet of the pavement, it is found necessary to repair more than one third of the area, or if the cracks in the brick exceed the proportion of 3 linear feet of cracks to 1 linear foot of pavement, all the brick shall then be taken up in the area included in the 300-foot lines and the curb lines, and shall be re-laid. During the last year of maintenance, any brick in the pavement shall show not less than one half the original width or thickness of such brick, and the wear or abrasion at the end of any brick shall not exceed more than three fourths of an inch"

795. The following is the method employed by the City of Albany, N. Y., in 1899.

"During the progress of the work, the city engineer shall weigh not less than fifty of the bricks of apparent average quality and appearance, and file a certificate of the result. During the ten-year guarantee period, the proper officer shall take up and re-weigh fifty brick from time to time, and whenever a 15 per cent loss of weight is found in any bricks on the street, they must be replaced with bricks as nearly as possible of the size and quality of the original."

CHAPTER XV.

COBBLE-STONE PAVEMENT.

797. A cobble-stone pavement consists of cobble stones or small bowlders placed side by side upon a bed of sand or upon the natural soil. Fig. 136 shows a transverse section of such

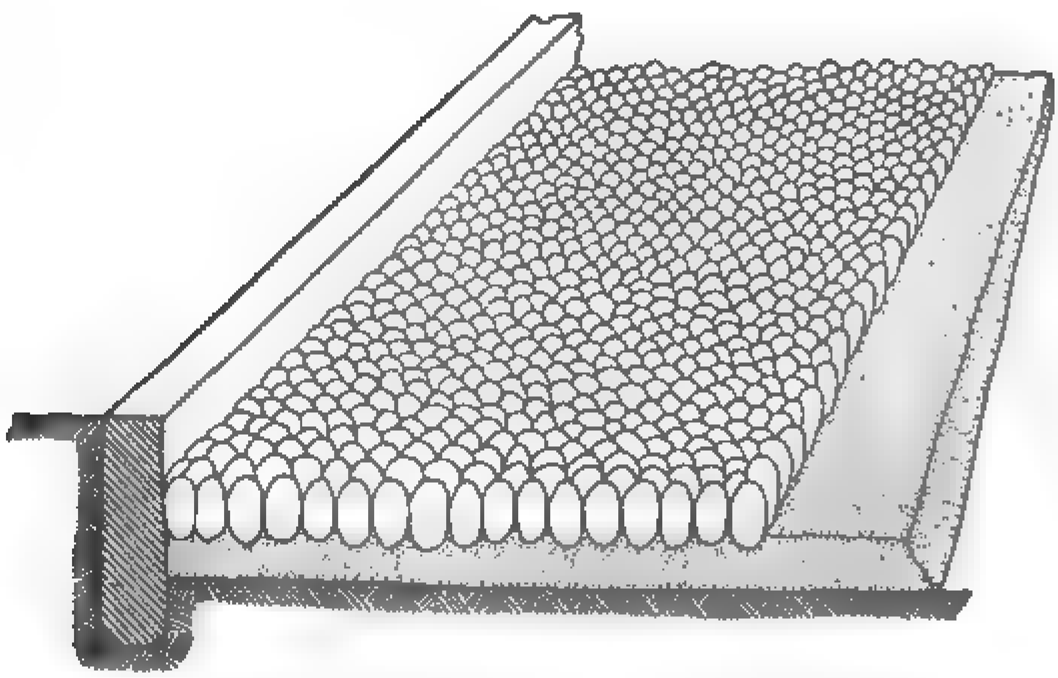

FIG. 136.—SECTION OF COBBLE-STONE PAVEMENT.

a pavement. The earliest pavements in many of the older American cities were of this form, and until recent years on account of their comparatively low first cost were quite common. In 1884, 93 per cent of all the pavements in Philadelphia were made of cobble stones; but in 1901 less than 6 per cent were of this kind. At present Baltimore has 321 miles of cobble-stone pavement,—more than any other city in the United States,—over 90 per cent of the pavements being cobble stones. In September, 1901, New York City still had 229 miles of streets paved with cobble stones, although they are rapidly being replaced with better pavements.

Since the introduction of asphalt and brick pavements, and since the decrease in the cost of stone-block pavement by the introduction of improved methods of quarrying, and since the decrease in the cost of crushed-stone roads by the invention of the machine rock-crusher and the steam road-roller, there is little excuse for the construction of cobble-stone pavements. The construction of such pavements have been practically abandoned, and in some cities it has been prohibited by law—like theft and murder.

However, because of their historic interest and because yards and alleys, and also gutters and crossings of unpaved streets are still sometimes paved with cobble stones, this form of pavement will be briefly considered. The ordinary European cobble-stone pavement is much superior to that of this country; but with a little care a cobble-stone pavement can be constructed which is much superior to that ordinarily seen in American cities.

798. GRADING. The earth, stone, and other materials necessary to be removed should be taken out for a depth of 12 inches below the top line of the finished pavement. All spongy material or vegetable matter remaining in the bed should be removed and be re-placed with clean sand or gravel, which should be well compacted by ramming or rolling. Upon the subgrade should be spread 5 inches of clean gravel, which should be firmly tamped or rolled. Upon this gravel bed should be spread a 3-inch or 4-inch layer of loamy sand to serve as a bed for the cobble stones. Loamy sand holds the stones better than that which is perfectly clean.

799. THE STONES. The stones should be hard, durable cobble or kidney stones, not less than 4 inches nor more than 6 inches long, and not less than 2 inches nor more than 4 inches in diameter. They should be sorted as they are brought upon the work, and the several sizes should be piled separately.

800. SETTING THE STONES. The work should proceed up grade and from the gutter toward the crown, and with the sides in advance of the center—so that the stones as laid will tend to crowd together and not apart. The paver should stand upon the stones already set, and should disturb the sand cushion as little as possible. With the hammer shown in Fig. 137, page 527, the paver makes a hole into which he sets a stone with its long axis vertical. No stone is to be laid on its longest side. It is usual to

give the required convexity to the surface by placing the largest stones in the middle of the street, and suitably graduating the sizes toward the sides. The stones are set as closely and compactly together as possible, and to a uniform grade; and should break joints as far as possible. After the stones have been set, all joints and cavities should be filled with pebbles and paving sand, and then the pavement should be carefully and thoroughly rammed until no further settlement occurs. The ramming is done with the rammer shown in Fig. 138, which weighs from 40 to 55 pounds. If in ramming, any of the stones do not come to the correct grade, they should be taken out, re-set, and again rammed. During the ramming the joints should be kept full of sand and pebbles; and when the ramming is completed, the surface of the pavement should be covered half an inch deep with paving sand.

FIG. 137.—COBBLE-STONE HAMMER.

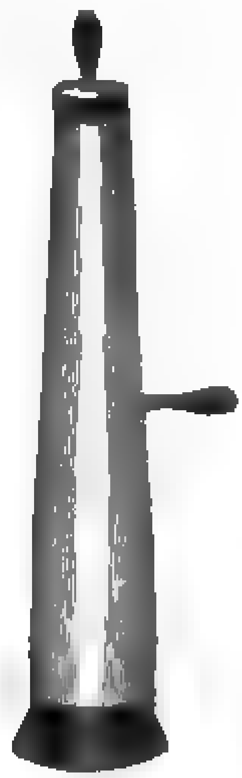

FIG. 138.—COBBLE-STONE RAMMER.

801. COST. The following is the cost of constructing cobble-stone pavements in Baltimore, Md., in 1901.

ITEMS.		COST PER SQ. YD.
Stones at $1.60 per perch of 2 800 lb.		$0.29
Paving sand at 60 cents per cu yd., delivered		0.20
Labor laying and ramming.		
1 foreman at $3 00 for 8 hours =	$3.00	
4 pavers " 3.00 " 8 " =	12.00	
2 rammers " 2.00 " 8 " =	4.00	
6 laborers " 1.66 " 8 " =	10.00	
Total for 200 sq. yds. =	29.00	0.14
Total cost		$0.63

802. MERITS AND DEFECTS. Low first cost is the only merit of a cobble-stone pavement. It is unstable, since it consists of double-curved surfaces in contact at points only, and the points of contact are seldom in the same horizontal plane. Its surface is hard to maintain, and the large joints are receptacles for filth.

CHAPTER XVI.

STONE-BLOCK PAVEMENT.

804. Nomenclature. The earliest pavements of ancient times consisted of irregular dressed blocks of stone more or less accurately fitted together. The form and size of the blocks have varied greatly from time to time, a fact which has given rise to different classes of pavements. A few of these will be briefly described.

805. Roman Roads. The Roman roads so frequently referred to by modern writers are the earliest examples of stone-block pavements. The details of construction varied somewhat, but as a rule they were about as follows: The foundation was laid in a trench about 3 feet deep, with no attempt at underdrainage. The base was formed of one or sometimes two courses of large flat stones laid in lime mortar, and was usually about 15 inches thick. Upon this was laid a 9-inch course of small fragments of stone imbedded in lime mortar, the intention of this course apparently being to bind together the tops of the large stones in the course below. Next was laid a 6-inch layer of concrete, apparently to make a smooth bed to receive the stones of the top course. The wearing surface consisted of closely-jointed, irregular-shaped stones, about 6 inches thick. The total thickness of the road was about 36 inches. In and near the cities, the top course was formed of irregular blocks of basalt, porphyry, or lava which had a top area of 4 or 5 square feet and a thickness of 12 to 15 inches, and which were dressed and fitted together with extreme accuracy and were imbedded in cement. These ancient pavements have aptly been described as "masonry walls laid on their sides."

The Romans seem to have located their roads in straight lines, running them toward prominent land-marks without much regard

to the topography or to natural obstacles. They were wasteful of materials and labor, which, however, cost nothing but the lives of captives who were forced to build these roads for the armies of their captors. The results were roads which are remarkable chiefly for their cost, and which were inferior to modern pavements costing only one quarter to one eighth as much. The durability of these roads does not seem so remarkable when it is remembered that the traffic was light, and consisted mostly of footmen, unshod horses, and ox-carts having wooden wheels, and also that probably the surface of the road was kept covered with earth two or three inches deep.

806. Russ Pavement. The earliest dressed stone-block pavement in this country was the Russ patent laid on Broadway, New York City, in 1849. This consisted of a 6-inch natural-cement concrete foundation on which was laid rectangular granite blocks, 10 to 18 inches long, 5 to 12 inches wide, and 10 inches deep, the sides of the blocks making an angle of 45 degrees with the line of the street.

807. Rubble Paving. In some cities having no cobble stones but having comparatively plenty of even bedded sandstone or limestone, the streets were paved by laying rough rubble stones flatwise, the stones being 4 to 6 inches thick and having a top surface of 4 to 6 square feet. The irregular joints between the stones were filled with spalls. The blocks chipped on the edges, wore round on top, and readily got out of place, thus making an exceedingly rough pavement.

808. Belgian Block. In Europe the first modern pavements were made of rectangular blocks having several square feet of top surface, which were laid lengthwise of the street; but as traffic increased it was found that the long joints, being parallel to the direction of the travel, rapidly wore into ruts and the pavement became rough and uneven. To obviate this, the blocks were made square and were laid with their sides at an angle of 45 degrees with the line of the street. It was soon discovered, however, that large blocks were not suitable for heavy traffic, as it was difficult to bed them so they would keep their place, and as their large surface did not afford a good foothold for horses. This led to the use of small square blocks laid with their edges parallel and perpendicular

to the line of the street. For many years this form of pavement has been very common in the cities of Europe, the blocks usually having a top surface 5 to 7 inches square and a depth of about 6 inches. This form of pavement seems to have been used first in the city of Brussels, Belgium; and in this country is known as Belgian pavement.

The Belgian block was introduced in this country about 1850, and for a time was much employed. The objections to the Belgian pavement are: 1. On account of the size and form of the blocks, it is difficult to keep them in place; 2, the blocks are of such a form as to give a poor foothold to horses; and 3, there is always a considerable length of joints parallel to the line of travel, which causes ruts to form in the pavement. Belgian blocks have usually been laid with their sides perpendicular and parallel to the sides of the street; but if a square block is to be used, it should be laid in courses diagonal to the street, so that no joints shall be parallel to the line of travel, a method which would add some extra expense. The Belgian block has been discarded in this country for the oblong block.

809. Guidet Pavement. This pavement consisted of stone blocks having a hexagonal top surface, the joints running perpendicular to the street being comparatively wide and those parallel with it being comparatively narrow. About 1869 a considerable amount of this pavement was laid in New York city and Brooklyn, at a cost of about $7.00 per square yard.

810. Standard Stone Block. At present the only stone paving-blocks employed in this country are 3 to 4 inches wide, 8 to 10 inches long, and 7 to 8 inches deep, and these are laid with their longest dimension perpendicular to the line of the street.

Stone-block pavements of any and all kinds are at present constructed much less frequently than formerly, brick or asphalt being employed instead; but it is probable that stone blocks will continue to be employed, at least for some time, on heavy traffic streets, and for medium traffic streets where suitable stone is plentiful and brick is expensive.

ART. 1. THE STONE.

811. As stone-block pavements are employed only where the traffic is heavy, the material of which the blocks are made should be hard enough to resist the abrasive action of the traffic, and tough enough to prevent being broken by the impact of loaded wheels. The hardest stones will not necessarily give the best results in the pavement, since a very hard stone usually wears smooth and becomes slippery, and the edges of the block chip off and the upper face becomes rounded, thus making the pavement very rough. A hard stone may be necessary under a heavy traffic, but under medium traffic a softer stone may give more satisfactory results.

The stone could be tested to determine its strength and durability much as paving bricks are tested, but it is not known that any such tests have been made. An examination of a stone as to its structure, the closeness of its grain, its homogeneity, etc., may assist in forming an opinion as to its value for use in a pavement; but in the present state of our knowledge, a service test in the pavement is the only certain guide.

Granite, trap, sandstone, and limestone have been used for paving blocks.

812. GRANITE. This is a massive, unstratified, granular rock composed essentially of quartz and feldspar, but almost always containing other components, such as mica, hornblende, and tourmaline in varying proportions. The quartz and the feldspar are called essential ingredients, since their presence is necessary to form a granite; while the other constituents are called accessories, since they merely determine the variety of the granite. The term granite is popularly applied to any feldspathic granular rock, and includes gneiss, syenite, and porphyry, or any crystalline rock whose uses are the same as granite. Gneiss is a rock of granitic composition that has a decided banding or parallel arrangement of its mineral constituents. Syenite is a granitic rock containing no quartz. Porphyry is popularly any fine-grained compact rock having large crystals scattered throughout its mass.

Granite varies in texture from very fine and homogeneous to coarse porphyritic rocks in which the individual grains are an

inch or more in length. The color may be red, dark mottled, light to dark gray or almost black. The durability is closely related to the accessory minerals present; and although granite is popularly regarded as the hardest and most durable stone, there are some notable exceptions. A quartoze granite, one in which quartz predominates, is too brittle for paving purposes; a feldspathic granite, one containing an excess of feldspar, is too easily decomposed; and a micaceous granite, one containing considerable mica in parallel lamina, is too easily split for use in paving blocks. Gneiss is usually too much stratified to make a good paving material. Syenite is one of the best materials for paving blocks, and usually the darker the color the better the stone.

The average specific gravity of granite is 2.66, and therefore the stone weighs 166½ pounds per cubic foot, or practically 2 tons per cubic yard. Granites ordinarily contain about 0.8 per cent of water, and are capable of absorbing about 0.2 per cent more. The crushing strength is quite variable, but usually lies between 15,000 and 20,000 pounds per square inch.

A most important property possessed by all granitic rocks is that of splitting in three planes at right angles to each other, so that paving blocks may readily be formed with at least nearly plane faces and square corners. So far as discovered, this valuable property is possessed only by the granitic and trappean rocks. This property is called rift or cleavage, and was caused by pressure before the rock was consolidated. The principal rift or plane of cleavage is always perpendicular to the line of pressure; and the character of the rift depends upon the amount of pressure and the grain of the stone. The fine-grained granites possess the most perfect rift, and it decreases as the size of the grains increase, so that a coarse-grained variety is likely to require considerable dressing to bring the faces of the blocks to a plane surface.

813. Granite paving blocks are produced in large quantities in Maine, California, Massachusetts, Wisconsin, Missouri, New Jersey, Pennsylvania, South Dakota, New Hampshire, and Georgia. The order in the above list is that of the number of blocks produced in 1889, the first two states producing more than all the others.*

* Eleventh Census of the United States.

In the last few years the production of granite paving blocks has greatly fallen off, apparently more than one half, probably owing to the substitution of asphalt and brick for stone blocks for paving purposes.

Maine, New Hampshire, Massachusetts and Connecticut abound in granite deposits suitable for the manufacture of paving blocks. "Rocks of a similar nature occur in the Blue Ridge section of the Appalachians as far south as Georgia, though in the more southern portions of the region the process of decay has extended so deeply as in general much to reduce their value as sources of paving blocks. Still, blocks of granite of good quality are quarried near Atlanta. In the Cordilleran district, there are many granite rocks which are likely in time to serve as sources of paving stone. It is probable that some of the granite materials in the Ozark district of Arkansas may also serve this need."

Granite is employed for paving blocks much more than any other variety of stone; and because of this fact, the term granite paving is generallly used as being synonymous with stone-block paving.

814. TRAP. This is a popular term applied to any dark-colored, massive, igneous rock. There are two varieties, diabase and basalt, which do not differ materially except in geological origin. Trap is hard, compact, and tough; and as a rule is finer-grained than granite, but is not so easily broken into regular shapes. Diabase is found in large quantities in the Palisades of New Jersey, and to some extent in Connecticut and Pennsylvania; and basalt is found principally west of the Mississippi, especially in California and Oregon. Owing to the difficulty of making them trap is not much used for paving blocks.

815. SANDSTONE. Sandstones are rocks made up of grains of sand which are cemented together by siliceous, ferruginous, calcareous, or argillaceous material. In most cases the cementing material determines the color, the various shades of red and yellow being due to iron oxide, the purple tints to oxide of manganese, the gray and blue tints to iron in the form of ferrous oxide or carbonate. The texture of the stone varies according to the sizes of the sand grains, of which there are all gradations from those that are so fine as to be barely discernible to those that are very coarse. The

hardness, strength, and durability of the stone is dependent upon the character of the cementing material. Only the harder and tougher sandstones, generally those in which the cementing material is siliceous, are used for paving. Sandstone paving blocks are common in the Lake and Western cities. The principal quarries from which sandstone paving blocks are obtained will be briefly described.

816. Medina Sandstone. This stone is found in the state of New York, extending from Oneida and Oswego counties on the east along the shores of Lake Ontario westerly to the Niagara river. It continues into Canada, and is found also to some extent in Pennsylvania and Virginia. It is generally a deep brownish red in color, though sometimes light and yellowish, and in a few localities gray. The coloring matter is oxide of iron. It is both fine grained and coarse grained in texture, the latter being of a deeper color as the iron cement more easily penetrates the interstices between the larger grains. The principal mineral constituent is quartz associated with some kaolinized feldspar. The cementing material is mainly oxide of iron with some carbonate of lime. The stone is evenly bedded, and the beds are divided into blocks by systems of vertical joints, generally at right angles to each other, an arrangement which greatly facilitates the work of quarrying. It has a specific gravity of about 2.60, and consequently it weighs about 148 pounds per cubic foot. It absorbs 2½ to 3½ per cent of water, but it is not materially affected by alternate freezing and thawing.

This stone is much used for paving in the Lake cities, where it is often preferred to granite since it does not wear slippery.

817. Potsdam Sandstone. This formation is worked at a number of places in the state of New York, but the largest quarries are near Potsdam. In general the stone is grayish, yellow, brown, and sometimes red in color, according to the amount and kind of iron in composition; and it varies in texture from a strong compact quartzite to a loosely coherent granular mass. That quarried at Potsdam is hard and compact, evenly grained, and reddish in color. It is largely used as a building stone and to a considerable extent also for pavements. It consists almost entirely of quartz and the cementing material is almost wholly silica.

818. Colorado Sandstone. In Boulder County, Colorado, are several deposits of sandstone that furnish stone for building and also for paving purposes. The stone varies in color from gray to a light red according to the composition of the iron compounds. It is found in layers varying from $\frac{1}{8}$ inch to several feet in thickness, splits easily, and breaks readily at right angles, so that it is formed into flagging, curb stones, and paving blocks without difficulty. It is hard and tough, and wears well in a pavement. Its grain and texture are such that, although it wears smooth, it is never slippery; and after a little wear it forms a smooth and pleasing pavement, very similar to one made of Medina stone.

819. Sioux Falls Quartzite. This is a metamorphic sandstone quarried at Sioux Falls, South Dakota. The stone is almost pure silica with only enough iron oxide to give it color, which varies from light pink to jasper red. It is very close grained, and will take a polish almost like glass. It is said to be the hardest stone in this country. Its crushing strength is about 25,000 pounds per square inch. It possesses a remarkably good rift and grain, although not as perfect as that of granite. It is used considerably as a paving material, being shipped as far east as Chicago; but it wears smooth with a glassy surface.

820. Kettle River Sandstone. This is a fine-grained, light-pink sandstone, found in large quantities at Sandstone, Minn., about a hundred miles north of Minneapolis, which has been used for paving purposes in Wisconsin and Minnesota. The stone wears flat, does not polish, and approaches granite in its resistance to crushing.

821. LIMESTONES. These differ greatly in structure, from a light friable variety highly charged with fossils to a hard compact rock denser and heavier than granite. They also vary in color according to the iron and carbonaceous compounds that may be present. The thin bedded varieties are easily broken into paving blocks. Although some varieties of limestone are very dense and strong, it wears unevenly when used as a paving material, and the blocks are speedily shivered by traffic and split by frost, owing to the fact that the lamination is vertical.

ART. 2. CONSTRUCTION.

Fig. 139 shows a transverse section of the better form of stone-block pavements.

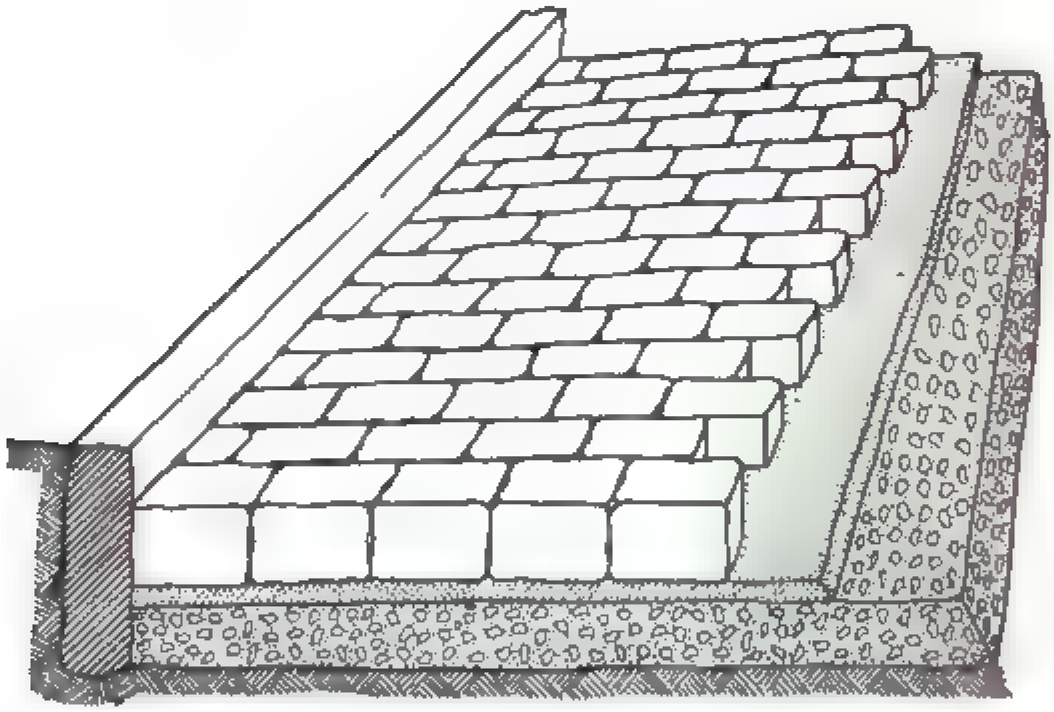

FIG 139.—SECTION OF STONE-BLOCK PAVEMENT.

822. FOUNDATION. The method of preparing the subgrade has already been discussed—see Art. 1, Chapter XII. Formerly the foundation always consisted of a bed of sand upon the natural soil (§ 565), but at present it is often a layer of concrete (Art. 2, Chapter XII). The sand foundation is cheaper, but with it the pavement does not keep its surface. At present stone-block paving is laid only on streets subject to heavy traffic, in which case a concrete foundation is specially desirable. Of course, if the subsoil is solid and not easily affected by moisture, it may be sufficient to lay the blocks upon the natural soil; but on account of the heavy traffic which stone blocks are intended to support, it is seldom wise to dispense with a concrete foundation.

823. SAND CUSHION. The thickness of the bed of sand upon which the blocks are laid should vary with the regularity of form of the blocks. Experience with brick pavements has abundantly proved that the sand cushion should be 2 inches thick; and as stone blocks are never as regular in form as brick blocks, the sand cushion for the former should never be less than 2 or 2½ inches, so as to give sufficient depth to bring the top of the blocks to a uniform surface.

A 2-inch sand cushion is usually employed, but experience with brick pavements seems to indicate that a thicker cushion would give a smoother pavement. The sand should be fine, clean, dry, and sharp. The sand should be fine, so as to make a smooth bed; should contain no clay or loam, so as not to be affected by moisture; should contain no organic matter so as to be incompressible; should be dry, so as to pack well; and should be sharp, since it is then less mobile. No great care is required in spreading the sand cushion, since it is likely to be considerably disturbed in setting the blocks. The sand is usually spread with shovels—compare § 763.

824. THE BLOCKS. The blocks should be made of sound and durable stone, free from weather marks and seams, and should be of uniform hardness, since the pavement will wear unevenly if hard and soft blocks are laid together. For the appearance of the pavement, it is desirable that blocks of only one color be laid together.

825. Dressing. The blocks should be split and dressed so as to have as nearly as possible plane rectangular faces and square corners. There is a marked difference in the regularity of paving blocks of different varieties of stone and also from different quarries of the same variety. As a rule stone paving-blocks are more carefully dressed in Europe than in America, but recently more attention has been given in this country to the form of the blocks. The more regular the blocks the thinner the joints, and consequently the smoother and more durable the pavement. In a general way, the ordinary stone-block pavement in this country has joints from $\frac{1}{2}$ to 1 inch wide with an average of about $\frac{3}{4}$ inch, while some of the better constructed pavements recently made have joints from $\frac{1}{8}$ to $\frac{3}{8}$ inch wide with an average of about $\frac{3}{8}$ inch. The surface of a recently finished pavement laid with ordinary blocks will show depressions of about 1 inch under a 3-foot straight edge laid parallel to the curb, while the most carefully dressed blocks will show about $\frac{1}{2}$ inch. Of course, these limits vary considerably with the variety of the stone. The two grades of paving as above are very common, the former being called ordinary stone block, and the latter specially dressed stone block.

The blocks should not taper much in any direction; and for

ordinary blocks it is often specified that the length of a block shall not differ at top and bottom by more than 1 inch, the width by more than ½ inch, and the depth by not more than ¼ inch. The faces should be free from lumps or bunches; and for ordinary blocks it is often specified that there shall be no projection greater than ½ inch, and for specially dressed blocks ¼ inch.

826. Size of Blocks. There has been much discussion as to the best dimensions for stone paving-blocks; but the proper size is a matter of judgment and does not admit of determination except within limits.

The width should be such as to give a good foothold for horses; and since the horse must depend for a foothold chiefly upon the shoe-calks' catching in the transverse joints of the pavement, the width of a block should be about equal to the distance between the toe and the heel calks of a horse's shoe. On the other hand, if the blocks are too narrow the number of transverse joints will be unduly increased and the pavement will wear rapidly and become rough.

The block should not be so long that it will fail to conform to the surface of the pavement, nor so short as to make too many longitudinal joints.

The depth should be sufficient to keep the block in position. It is usually assumed that this is 6 inches, but the stability of the block varies greatly with the manner of filling the joints (§ 832), and it is quite probable that since the substitution of tar or hydraulic cement as a joint filling material a less depth would suffice. Not infrequently the depth is made greater than is necessary for stability, to allow for wear; but before any considerable depth is worn away, the blocks become very uneven and rough, and the pavement should be re-laid. The blocks may then be taken up, and be re-dressed, and be laid again. In America the depth of adjoining blocks is usually allowed to vary as much as 1 inch, while in England the limit is ¼ inch. The wide variation in the depth of adjoining blocks is the most common cause of the great roughness of ordinary stone-block pavements, the shorter block having the greater depth of sand under it settles more than its deeper neighbor.

Table 53 gives the dimensions of stone paving-blocks employed in various cities.

TABLE 53.

SIZES OF STONE PAVING-BLOCKS.

Ref. No.	Cities.	Dimensions, in Inches.		
		Width.	Length.	Depth.
	American:			
1	Albany, N. Y.	3 –4½	8 –14	7 –8
2	Baltimore, Md.	3 –4	9 –12	6 –7
3	Boston, Mass., small	3½–4	6 – 8	7½–8
4	" " large	3½–4½	8 –12	7½–8
5	Buffalo, N. Y.	3 –4¾	7 –12	6½–7
6	Cambridge, Mass.	3½–4	7 – 8	7½–8
7	Chicago, Ill.	3½–4½	8 –10	6
8	Cincinnati, O.	3 –4½	8 –12	6 –7
9	Cleveland, O.	3¼–5	8 –13	6 –6½
10	Columbus, O.	3 –5	6 –12	6 –7
11	New Haven, Conn.	3½–4½	8 –14	7 –8
12	Newark, N. J.	3½–4½	8 –12	7 –8
13	New York, N. Y.	3½–4½	8 –12	7 –8
14	Philadelphia, Pa.	3½–4½	8 –12	6 –6½
15	Pittsburgh, Pa.	3½–4½	6 –10	6 –7
16	Providence, R. I.	3 –4	8 –12	7 –8
17	St. Louis, Mo.	3½–4½	9 –12	7½–8½
18	Washington, D. C.	3 –5	6 – 8	5½–6
	Foreign:			
19	Berlin	7½–7⅞	7½–7⅞	7½–7⅞
20	Liverpool	3¼	3¼	6¼
21	London	3 –4½	8 –14	6
22	Manchester	3 –3½	5 – 7	6 –6½
23	Paris, large	6¼–9	9	9
24	" medium	5½–7	6 – 8	6 –8
25	" small	4¼–5½	6 – 8	4¼–7
26	Vienna	7¼	7¼	7¼

827. Usually the contractor buys the blocks by the thousand, but gets paid for them by the square yard; and therefore it is to his financial advantage to use as many large blocks as possible. Again, the man who sets the blocks is usually paid by the square yard, and therefore it is to his financial advantage to make the joints as wide as he may. It is very undesirable that it should be to the financial interests of the contractor and of the paver to secure a poor pavement, i. e., one having large blocks and wide joints. An excess in the width of the block is more important than

in the length, since it is proportionally a larger matter, and also since it has a more important influence upon the quality of the pavement; and therefore special care should be taken to prevent an excessive width of blocks or too thick side-joints. To identify as far as possible the interests of the contractor with those of the city, the following method of measuring a stone-block pavement has been proposed.*

"The blocks must be substantially smooth and square on all their faces, and within the limits of the following dimensions: Not less than 3½ inches, nor more than 4½ inches wide across their upper and lower faces; not less than 7 nor more than 8 inches deep; and not less than 8 nor more than 14 inches long, except where shorter stones are necessary to fill out courses.

"The sum to be paid per square yard shall be ascertained as follows: The number of blocks per square yard upon which the bid of the contractor is based shall be 22½. The actual average number of blocks laid per square yard shall be determined as follows: The City Engineer shall from time to time, during the progress of the work, measure the width of 50 to 100 courses, and from this deduce the average width of a course. The average length of the blocks is hereby fixed for the purpose of computing the number of blocks laid per square yard, at 12½ inches.†

"For each block or fractional part thereof that the average number laid per square yard shall exceed 22½, there shall be added to the contractor's bid per square yard an amount computed at the rate of 9½ cents per block. For each block or fractional part thereof, that the average number laid per square yard shall fall short of 22½, there shall be deducted from the contractor's bid per square yard an amount computed at the rate of 9½ cents per block."

According to this method, if the contractor uses narrow blocks and thin joints, the price per square yard is proportionally increased; but if he uses thick blocks and wide joints, the price per yard is decreased. To meet the case in which a contractor should buy large blocks at a considerable reduction, it might be wise to make the amount per block to be deducted greater than that added. For convenience in applying the above method, a table is computed which gives in one column the width of 50 courses and in a second column the corresponding number of blocks per square yard. Of

* By Horace Andrews, City Engineer of Albany, N. Y., in 1890 in *Engineering Record*, Vol. 21, p. 314 and 329; Vol. 25, p. 110-11.

† This value was determined by measuring a number of blocks in pavements laid with blocks of the size stated above.

course, the number of blocks to a square yard would vary with the specified dimensions of the blocks and with the width of joints, which latter would vary with the different kinds of stone and even with the same kind from different quarries, and could be determined in any particular case only by measuring the combined width of a number of courses of blocks in the pavement. The normal or contract number of blocks per square yard should be stated according to the quality of work desired.

Some cities buy the blocks and contract for laying them, a method which eliminates the interest of the contractor in using large blocks. In some cities it is the custom for the contractor to buy the blocks by the square yard in the pavement, in which case the contractor pays only for the blocks accepted, and has no financial interest in the size of the blocks or the thickness of the joints. In Great Britain it is customary to buy the blocks by weight, a method which eliminates any interest of the contractor in the size of the blocks.

828. Some cities require the blocks to be inspected and sorted to sizes before being piled on the street. The advantages of this are: (1) when stacked upon the street, only the outside blocks of the pile can be inspected; (2) when the blocks are being laid, the inspector has enough to do to watch the quality of the workmanship without having also to inspect the blocks; (3) removing rejected blocks from the pavement delays the opening of the street; and (4) if the blocks are sorted before being piled upon the street, different sizes are not so likely to get into the same course, and therefore the joints will be narrower.

In Cleveland, Ohio, where the specified width of the stone paving-block is from 3½ to 5 inches, the blocks are sorted into three classes. Class No. 1 includes blocks from 3¼ to 3½ inches, Class No. 2 blocks from 3¾ to 4¼ inches, and Class No. 3 embraces blocks from 4½ to 5 inches. Blocks in Class No. 1 are marked with red paint, blocks in Class No. 2 with blue paint and those in Class No. 3 with black paint, so that when the blocks are delivered on the street each class can be easily recognized and laid by themselves in the pavement.

Some cities specify that thinner blocks shall be used on steep grades than on level portions, to improve the foothold.

829. Setting the Blocks. In placing the blocks, the workman should stand upon the finished work, that the sand cushion may not be disturbed; but he usually stands on the sand cushion, the blocks being piled on the sand bed behind the paver. The workman with the pointed end of the hammer shown in Fig. 140, excavates a hole, if need be, into which to set the block.

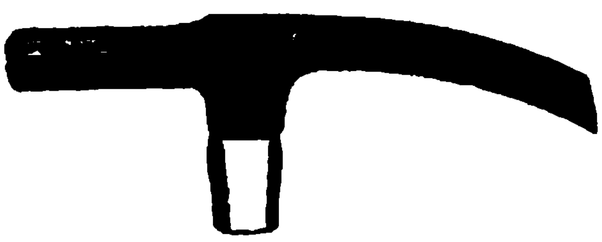

Fig. 140.—Stone Paver's Hammer.

To secure the proper form to the surface of the pavement, a chalk line is made upon each curb or a string is stretched in each gutter to indicate the top of the blocks, and a row of blocks 20 to 25 feet apart is set in the center of the street with their tops to grade, as determined by measuring down from a string stretched from curb to curb. If the street is wide, one or more rows of blocks are placed between the curb and the crown. Ordinarily the surface of the pavement is brought to grade between the guide blocks with the unaided eye; but in the best work, a straight edge or string is placed parallel to the line of the street on the guide blocks, by which to grade the surface, and between these lines the blocks are brought to the surface indicated by a straight edge parallel to the line of the street resting upon the pavement already completed.

The blocks should be set with their long dimension across the street, except at street intersections; and should be placed in straight rows with as close joints as possible. Each course should be formed of blocks of uniform width and depth; and the bond should be approximately half the length of a block, or at least 3 inches. As the blocks are of uneven lengths, the securing of the proper bond will require careful attention. The paver is instructed to secure thin joints, and consequently has a tendency to set the block with the larger end up; but when set in this way the block will surely sink under traffic. Placing the large end of the block down makes a wide joint, which is objectionable if the joints are to be filled only with sand and pebbles (see § 832), but is no serious objection if the joints are to be filled with hydraulic-cement grout (see § 832).

The courses at street intersections are arranged substantially as in brick pavements (see § 768). The work should progress up

grade and from the gutter towards the crown, so that the blocks may have no tendency to settle away from each other and thus increase the width of the joints.

830. RAMMING THE BLOCKS. After the blocks have been placed, they should be thoroughly rammed until they come to a firm bearing. As a rule the workman is more interested in securing a uniform surface than in bringing the blocks to an unyielding bearing. Each block should receive at least three hard blows — one near each end and one in the middle. The rammer employed, Fig. 141, weighs from 50 to 90 pounds, ordinarily 60 to 75 pounds.

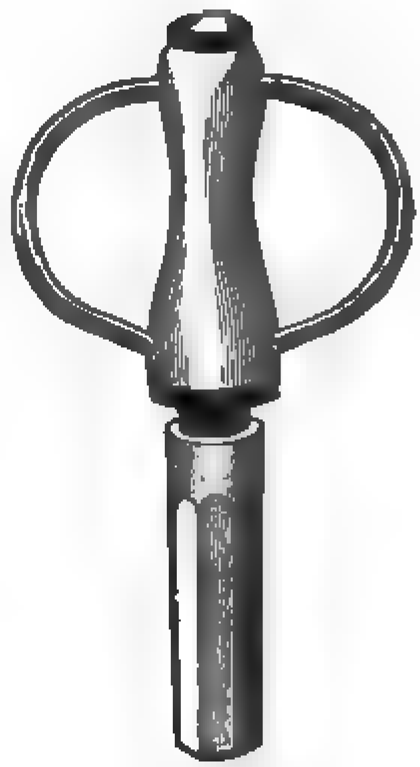

FIG. 141.—STONE-BLOCK RAMMER.

If, after being rammed, a block does not conform to the general surface of the pavement, it should be lifted out, and sand should be added to the sand bed or extracted from it to bring the top of the block to the proper elevation. Any imperfect or broken blocks should be removed and be replaced with perfect ones. Finally each block should be adjusted so that it stands perpendicular to the sand bed and has its top face conforming to the surface of the pavement. The quality of the pavement depends largely upon the care with which this adjustment is made.

To secure a thorough ramming of the pavement, it is sometimes specified that there shall be one rammer to each paver, and occasionally one rammer to two pavers. No ramming should be allowed within 20 or 25 feet of the course last laid, to prevent the tipping of the blocks out of the vertical position.

831. FILLING THE JOINTS. After the blocks have been rammed, the joints are swept full of pebbles. For ordinary stone blocks, it is usually specified that the pebbles shall pass a sieve having a $\frac{3}{4}$-inch mesh and be retained by a $\frac{1}{4}$-inch mesh. If the pebbles are too small, they will not permit the tar or cement grout, with which the joints are to be filled, to flow freely to the bottom of the joint. After the joints have been filled with these pebbles,

they are tamped with a bar having a chisel-shaped end. The joints are then again swept full of pebbles and again tamped.

832 Three methods are in more or less common use for completing the filling of the joints.

1. The filling of the joints is completed by spreading fine sand over the pavement to a depth of ½ to 1 inch, and allowing traffic to work it into the joints. Until recently this was the only method employed, and even yet it is by far the most common. When filled in this way, the joints are not impervious; and the filling does not aid much in keeping the blocks in position.

2. Recently it has become the custom with the better class of stone-block paving to complete the filling of the joints by pouring hot tar, or a mixture of tar and asphalt, over the pebbles. The tar is applied in substantially the same way as in the case of brick pavements—see § 775. The pebbles should be perfectly dry, for an almost inappreciable amount of water will cause the tar to foam and will prevent it from adhering to the pebbles and from forming a solid joint. It may be necessary to dry the pebbles artificially. The tar must not be applied when the pebbles are very cold. The joints should be entirely filled with the tar, to secure which it is usually necessary to pour the joints twice. To keep the contractor from having a financial interest in not filling the joints entirely full, it is sometimes specified that there shall be brought upon the ground not less than a stated number of gallons of paving cement for each square yard of pavement, whatever remains after the completion of the work being the property of the city.

The quantity of tar required to fill the joints varies from 1 to 3½ gallons per square yard, according to the width of the joints, which varies with the quality of the stone and the workmanship.

The tar in the joints makes the pavement impervious, and therefore more sanitary. The tar also assists in keeping the blocks in position, and therefore adds to the durability and smoothness of the pavement.

3. In a comparatively few instances, the joints have been filled with Portland-cement grout, which should be mixed and applied as described for brick pavement—see § 777. The hydraulic-cement grout makes the joint impervious, holds the blocks firmly in position, prevents the edges from chipping and the top

face from wearing round, and adds materially to the smoothness and durability of the pavement.

833. MAXIMUM GRADE. Stone-block pavements are freely employed upon grades up to 10 per cent, and if the stone is a quality that does not wear smooth, they may be used upon grades up to 15 per cent.*

It has been recommended that on steep grades to afford a good foothold for the horses, (1) the edges of the blocks be chamfered, (2) that the joints be comparatively wide, and (3) that the joints be filled to within about an inch of the top with cement mortar. It is not known that this expedient has ever been employed; but the probabilities are that wide joints would be equally as effective without chamfering the blocks, since the edges spall off soon when the joints are wide and are filled with either gravel or tar. Further, the accumulation of dirt in the wide joints would probably largely neutralize their effect. Fig. 142 shows another method that

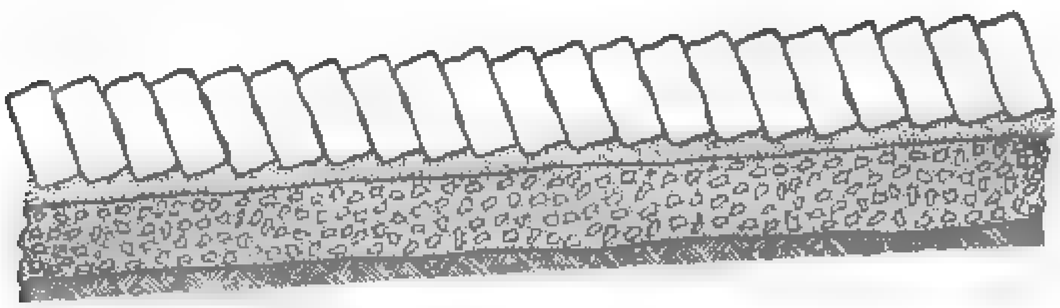

FIG. 142.—STONE-BLOCK PAVEMENT ON STEEP GRADE.

has been proposed, but it is not known that it has ever been tried.

834. MERITS AND DEFECTS. The only merit claimed for stone-block, particularly granite-block, pavement is durability. The material of the blocks does not decay or wear entirely out; but the blocks wear rounding and slick on top, and get displaced, so that the pavement becomes excessively rough, noisy, and slippery. Even the best stone-block pavement is rough, noisy, and difficult to keep clean.

835. COST. The price of stone paving blocks varies with their size and the quality of the stone. According to the U. S. Eleventh Census, the average price of granite blocks at the quarry varies

* See § 479.

in the different states from $32.32 to $78.67, although the range is usually between $40 and $60; the average price per thousand for the entire country is $48.17. Table 54 gives the cost of various sized granite blocks at Quincy, Mass.

TABLE 54

COST OF GRANITE PAVING-BLOCKS F. O. B. QUINCY, MASS.

Ref. No.	Dimensions in Inches.			Number per Sq. Yd.	Cost per Thousand.
	Width.	Length.	Depth.		
1	4½–5	10–14	6–8	23	$50.00
2	4½–5	10–14	6	23	47.50
3	4½–5	7– 8	6–8	35	40.00
4	4½–5	6– 8	6	35	35.00

836. The average cost to the contractor of laying *specially dressed* granite blocks (3½ to 4 inches wide, 8 to 10 inches long, 5 inches deep, of which 28 to 31 lay a square yard) at Chicago in 1902 was about as follows:

ITEMS.	COST PER SQ. YD.
Concrete, 6 inches: materials and labor	$0.55
Sand cushion, 2 inches: material at $2.00 per sq. yd	.10
labor spreading	.02
Blocks: cost f. o. b. Chicago	2.15
hauling to street	.10
carrying to paver	.03
laying and ramming	.13
Filling joints: paving gravel at $2.00 per cu yd	.11
labor spreading	.03
tar at 9 cents per gallon	.09
labor applying	.06
Total cost to contractor	$3.37

Ordinary granite blocks cost 25 to 30 cents per square yard less than the special dressed blocks above, and the cost of laying is 8 cents per square yard less, and the total of the other items is substantially as above, thus making the total cost of the *ordinary* granite-block pavement on concrete foundation about $3.00 per square yard.

837. In New York city the cost of ordinary granite-block pavement is as follows:

Items.	Cost per Sq. Yd.
Concrete, 6 inches: materials and labor	$0.55
Sand cushion, 2 inches: material at $1.00 per cu. yd	.05
labor spreading	.02
Blocks: 22½ at 5 cents on street	1.24
labor laying	.12
Joint filling: 3½ gallons of tar at 7 cents	.24
labor applying	.03
paving gravel, 1¼ cu. ft	.09
Total cost to contractor	$2.34

838. The cost of Medina sandstone paving at Rochester, N. Y., in 1902 was as follows: *

Items.	Cost per Sq. Yd.
Concrete, 6 inches: materials and labor	$0.50
Sand cushion, 2 inches: at $1.08 per cu. yd. in place	.06
Blocks, 6 inches deep: cost f. o. b. quarry	1.15
freight to Rochester	.07
loading and unloading	.10
hauling 1 mile	.05
distributing and sorting	.03
laying	.06
Filling joints: 0.02 cu. yd. sand at $1.00	.02
1½ gallons of tar at 10 cents	.15
labor applying	.06
Superintendence: foreman at 40 cents per hour for 30 sq. yds	.013
2 water and errand boys	.007
Total cost to contractor	$2.40

839. In Liverpool, England, the cost of a pavement of granite blocks 3 inches wide, 5 to 7 inches long, and 7½ inches deep, with tar-filled joints, is as follows: †

Items.			Cost per Sq. Yd.
0.31 ton granite "sets," 7½ inches deep,	at $6.72,	including cartage,	$2.08
0.064 " gravel for bedding,	" 1.56,	" "	.10
0.015 " coal-tar pitch,	" 7.20,	" "	.105
0.6 gallon dead or creosote oil,	" 0.30,	" "	.02
0.002 ton coke for heating tar,	" 2.88,	" "	.005
0.018 " shingle, dried and riddled,	" 1.68,	" "	.03
Labor			.17
Total, exclusive of administration, tools, etc			$2.51

* *Engineering News*, Vol. 48, p. 70.

† Proc. Inst. of Civil Engineers, Vol. 58, p. 7.

If the joints are filled with gravel only, the cost is as follows:

Items.				Cost per. Sq. Yd.
0.31	ton granite "sets,"	at $6.72,	including cartage,	$2.08
0.096	" gravel for bedding, 1 inch thick,	" 1.56,	" "	.18
0.02	" " " joints,	" 1.44,	" "	.05
Labor	....			.10
	Total, exclusive of administration, tools, etc..................			$2.41

CHAPTER XVII.

WOOD-BLOCK PAVEMENTS.

840. Wood appears to have been employed as a paving material first in Russia, where, though rudely fashioned, it has been used for some hundreds of years. Wood pavements were first laid in New York city in 1835–36, and in London in 1839. Wood-block pavements are constructed less frequently in this country now than formerly, the decrease being probably due in part to the introduction of brick pavements. Within the past two years, however, wood pavements seem to be growing somewhat in favor.

ART. 1. THE WOOD.

841. VARIETIES. Both the hard and the soft varieties of wood have been employed for making paving blocks. The hard woods are used without preservative treatment, and the soft ones are used both with and without preserving (see § 844). In the United States, cedar and cypress, on account of their abundance, cheapness, and durability against decay, are more generally employed. In Europe nearly all varieties of the pine species have been tried, as well as oak, ash, elm, and gum; but Baltic fir, Indian teak, and Swedish deal seem to be the favorites. Within the past few years, two Australian hard woods, jarrah and karri, have been introduced in London for paving purposes, and have been favorably received.

None of the woods employed for making paving blocks need a description, except perhaps the Australian hard woods, jarrah and karri.

842. Jarrah and Karri. Jarrah is short grained and free splitting, and breaks with a clean fracture and burns with a black ash. In color it looks nearly like cherry. When seasoned, it has a specific gravity of 1.01 and absorbs about 10 per cent of water when im-

mersed 48 hours.* Its transverse and crushing strength is about the same as that of English oak and Indian teak.

Karri is interlocked in the grain and is difficult to split; it splinters in breaking and burns with a white ash. It is a little lighter colored than cherry. When seasoned, it has a specific gravity of 1.12, and absorbs about 7 per cent of water when immersed 48 hours. Its transverse strength is a little greater than that of English oak or Indian deal, and its crushing strength is considerably greater.

For street paving, there is little difference between jarrah and karri, although for exceptionally heavy traffic karri shows slightly less wear. Karri shrinks less than jarrah. Both timbers are very plentiful in Western Australia, the trees growing with large, long, straight bodies without limbs. Jarrah and karri are preferred in some vestries of London to any other form of wood paving-blocks.

843. QUALITY OF WOOD. Whatever the variety of the wood, it should be sound, close-grained, uniform in quality, free from sap and knots and from the blue tinge which is a sign of incipient decay.

844. PRESERVATION OF WOOD. A wood pavement fails through wear and decay. A number of methods have been invented for increasing the durability of timber against decay; and although these methods have been employed to a considerable extent for preserving piles, railroad ties, and bridge timbers, they have been used only to a limited degree in this country for preserving paving blocks.

Experiments in wood preserving date back some centuries, and the list of substances experimented with seems nearly endless; but there are only a few antiseptics that have stood the test of time or have been worked commercially. According to the antiseptic employed, the principal methods of preserving timber may be grouped into four classes:

1. Kyanizing—use of corrosive sublimate.
2. Burnettizing—the use of chloride of zinc.
3. Boucherizing—the use of sulphate of copper.
4. Bethellizing—the use of creosote oil.

* Most soft woods will absorb 20 to 25 per cent.

The only one of these methods that is suitable for preserving wood paving-blocks is the last, since the mineral salts used by the others wash out. There are various methods of using the above antiseptics, as applying externally with a brush, steeping or immersing, exposing to vapors, injecting in closed tanks under pressure, etc.; but the only method employed for paving blocks is that of injecting the creosote under pressure.

845. Creosoting. This process consists of impregnating the wood with the oil of tar, called creosote, from which the ammonia has been expelled. The effect is to coagulate the albumen and thereby to prevent its decomposition, and also to fill the pores of the wood with a bituminous substance which excludes both air and moisture, and which is noxious to the lower forms of animal and vegetable life.

The timber to be preserved should be thoroughly seasoned. It is then put into a closed cylinder, and the air is exhausted. Hot creosote is allowed to flow in; and when the cylinder is full, a force-pump is applied and the pressure raised to 150 or 200 pounds per square inch. The wood remains under pressure until it has absorbed the requisite quantity of oil, as indicated by a gage on the tank. For protection against decay, it is necessary to inject from 8 to 12 pounds per cubic foot. The woods which are best adapted to this treatment are those which are most absorbent, and therefore the easiest and quickest destroyed, as the gums and cottonwoods. Cypress, cedar, pine, and porous oaks are absorbent and can be successfully treated. Creosoting is quite expensive owing to the cost of the creosote and to the expense of injecting it, the cost being from $12 to $18 per 1,000 feet, board measure.

Creosoted paving blocks have been laid during the last five or six years in several Western and Southern cities, notably Indianapolis, Terre Haute, Galveston, and New Orleans. In Indianapolis the experience of six years' service has been highly satisfactory, the pavement showing increased popularity over all other forms of roadway. Creosoted wood blocks are exclusively used in Paris and much used in London.

846. Creosote is a good preservative, but evaporates and is washed out by the rains. To remedy these defects, two modifi-

cations of the above process have been recently introduced. One is called the kreodone-creosote and the other the creo-resinate process.

847. *Kreodone-Creosote Process.* This consists in impregnating the seasoned blocks under pressure with an oil derived from creosote oil which possesses the original preservative properties with a longer endurance, and which also has the effect of forming a varnish-like film or coating on the outer surface of the wood, thus protecting it from the elements. The blocks are sterilized by subjecting them to dry heat of 240° F. for eight hours. The kreodone oil is then forced into the fibers of the wood, under a pressure of 70 pounds per square inch, maintained for two or three hours, until 12 pounds have been absorbed by each cubic foot of the wood. The advantage claimed for this process over ordinary creosoting is that the kreodone creosote is not as easily washed out or as easily volatilized as creosote.

Samples of this pavement were laid in 1901 in Chicago on Michigan Avenue in front of the Auditorium Hotel, and in Indianapolis on North Delaware Street.

848. *Creo-Resinate Process.* The special feature of this process is the mixing of dead oil of coal tar (creosote) with melted resin and formaldehyde. The resin is used to render the wood waterproof, and to prevent the washing away of the mixture; and the formaldehyde is used to strengthen the antiseptic nature of the compound. The creo-resinate mixture is applied hot under pressure, and is followed, in another cylinder, by the injection of hot milk-of-lime under pressure, in order to fix and set the creosote.

It is claimed that this process increases the density of the wood and also its resistance to impact and abrasion over either untreated or creosoted wood.* It is further claimed that the more porous blocks take up more of the creo-resinate mixture than the denser ones, and consequently increase in density and strength to a greater degree, the process thus making the blocks more uniform in quality. This is probably true, but only in a slight degree.

Pavements treated by this process have been laid within the past two years in Boston † and Springfield, Mass., and in Baltimore, Md., and seem to be giving satisfaction.

* Trans. Amer. Soc. Civil Eng'rs, Vol. 44, p. 181–193.

† Proc. Amer. Soc. of Municipal Improvements, 1901, p. 212–17.

849. Value of Preserved Wood for Pavments. If the pavement on a particular street is worn out by traffic before the wood has time to decay materially, then except in so far as the treatment adds to its strength, the preservation of the wood will be ineffective; but if the deterioration due to decay is considerable, then the preservative treatment may add to the life of the pavement. There is considerable difference of opinion as to the relative value of treated and untreated wood for paving purposes. The relative merits of the two vary with the climate, the amount of traffic, the kind of wood, and the cost of treatment; and an economic solution of this problem is dependent upon the cost of both forms of wood-block pavement in comparison with the various other kinds of pavements. Some vestries in London, where there are large areas of both treated and untreated wood-block pavements, favor preserved soft-wood blocks and some unpreserved hard-wood blocks—all apparently under substantially the same conditions. Paris, which also has large areas of wood pavements, seems to favor blocks impregnated with 8 to 10 pounds of creosote per cubic foot.

850. In this country and in London, there has been not a little discussion concerning the relative merits of untreated Australian hard wood and treated soft wood as a paving material for the streets of London.* The engineers of some vestries prefer the one and some the other, but a significant fact is that the loans made by the London County Council (the central governing board) to the vestries for paving purposes are payable in the case of soft-wood paving in 5 years, and in the case of Australian hard-wood in 12 years.

ART. 2. THE CONSTRUCTION.

851. Much ingenuity and inventive genius has been exercised to discover some odd or novel way to cut and lay the blocks, twenty-five or thirty patents having been issued in this country during the first twenty-five or thirty years of the history of wood-block pavements. More attention appears to have been given to the form of the block than to the strength and durability of the wood. All of these complicated forms have been forgotten, and

* *Engineering News*, Vol. 43, p. 358; Vol. 44, p. 126–27, 409; Vol. 46, p. 107.

now the only ones used are cylinders, and parallelopipedons, the former frequently being called round blocks and the latter rectangular or square blocks. The fiber of the wood is always set vertical.

A. ROUND WOOD-BLOCK PAVEMENT.

852. This pavement consists of short sections of cylindrical blocks set with the grain vertical, side by side as close together as possible. Fig. 143 shows a cross section and a perspective of this form of pavement.

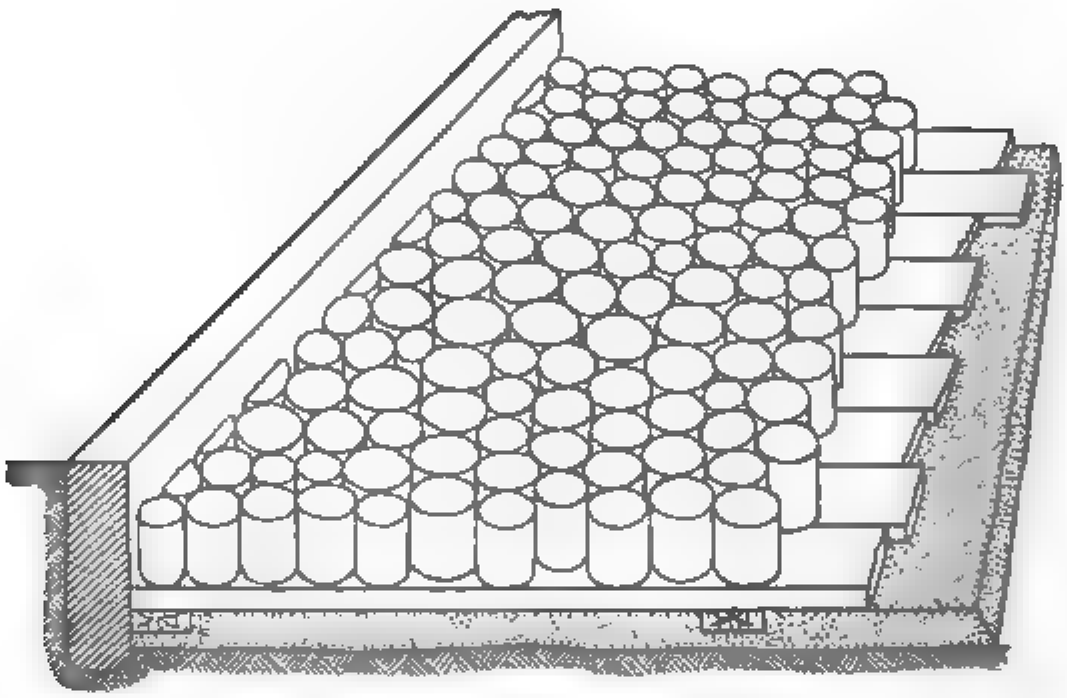

FIG. 143.—ROUND WOOD-BLOCK PAVEMENT.

853. FOUNDATION. The blocks are sometimes set directly upon the native soil, after it has been properly shaped and rolled; and sometimes upon a layer of sand.

The usual and best foundation is constructed by spreading a layer of coarse sand, about 3 inches thick, upon the prepared subgrade. Boards, 1 inch thick and 8 to 12 inches wide, are then laid lengthwise of the street from curb to curb, usually 8 feet apart, and are carefully bedded in the sand to the true cross section of the roadway. These boards are to support the ends of the planks which form the foundation for the blocks. After the stringers are in place and well tamped, a straight edge or scraper reaching from one stringer to another is drawn from one side of the street to the other, thus leveling the sand flush with the top of the stringers.

If the sand is damp, it should be compacted by ramming. It is well to leave the sand a little higher than the stringers, in order to be sure that the foundation boards have a perfect support upon the sand throughout their entire surface. Sand can easily be fitted to the true surface, while it would be almost impossible to grade clay or loam as evenly. The sand also assists in draining away any water which percolates through the paving.

On the stringers and the sand, the foundation planks are laid close together, across the street, the ends abutting on the stringers. These planks should be a fair quality of well seasoned lumber; and are usually 1 inch thick, but occasionally 2 inches thick, and sometimes are coated with hot tar. If the board is well seasoned and perfectly dry, the coal tar will increase the durability of the material; but if there is any sap or any moisture in the lumber, the coal tar would effectually seal it up and hasten dry rot on the inside.

854. Round blocks are occasionally laid upon a concrete foundation, but such construction is not advisable under ordinary conditions. Round wood-block pavements are justifiable only where low first cost is absolutely necessary, in which case a concrete foundation is inappropriate.

855. THE BLOCKS. These are prepared by sawing sections 6 inches long from poles 4 to 8 inches in diameter. The wood is usually red or white cedar,* although tamarac, yellow pine, and cypress are sometimes used. Cedar is more durable in wet ground than any other wood. Generally the bark is removed from the poles before cutting them into paving blocks; but about 1880 there was invented a machine for removing also the sap. Machine-made sapless blocks are truly circular and the same size at both ends, and fit together much more closely than rough irregular undressed blocks, and hence make a smoother pavement. Ordinary cedar blocks have from 25 to 35 per cent of sap, and as the sap is less durable against decay than heart wood and has less strength to resist crushing under traffic, the sapless blocks do not wear round on the top face as rapidly as the undressed blocks. Sapless blocks were laid to a considerable extent in Saginaw and

* The timber known as white cedar in the North is called juniper in the South.

other cities in Michigan from 1880 to 1890; but owing to the increasing price of timber, and to the introduction of brick pavements, and to the decrease in the cost of asphalt pavements, they are not now laid. At the factory in East Saginaw, machine-made sapless cedar blocks cost about 10 cents per square yard more than undressed blocks.

856. Laying the Blocks. The blocks are placed on end close together upon the plank foundation, and are packed in such a way that the spaces between the adjoining blocks have only three sides rather than four or more. The closest packing gives triangular spaces. Projecting knots or bunches on the side of the block should be cut off, so that the blocks may stand close together. Occasionally it is necessary to split off a piece of a block in order to make it fit up closely against the adjoining ones; but no portion of a split block less than 3 inches in diameter should be used, and the edges of split blocks should be cut away so as to be not less than 1 inch thick at the thinnest part. Two split surfaces should not be laid in contact with each other. In paving against the curb, each alternate block should be split in halves, and the straight side be placed against the curb. In no case should blocks having the same diameter be set in a row across the street, but the various sizes should be intermingled with each other.

After the blocks are in place, the spaces between them are filled with pea gravel. Sometimes the gravel is simply swept into the joints, a surplus being left upon the surface to be worked in further by traffic; and sometimes the gravel is tamped into place; and in a comparatively few cases, tar or paving cement is poured upon the pebbles in the joints. If the gravel is tamped into place, there should be two men tamping for each one laying blocks. The tar makes the joints impervious and also assists in preventing the blocks from being displaced by traffic or from being floated away when the pavement is flooded. If paving cement is used, the blocks and the gravel should be perfectly dry. The hot tar in coming in contact with moisture forms steam which blows the tar full of bubbles and destroys its cementing power. The entire surface of the pavement is finally covered with about 1 inch of fine roofing gravel, which should be heated in order that it may bed itself into the tar.

857. COST. In Chicago in 1900, a 6-inch cedar-block pavement on 2-inch hemlock planks which rest on 1-inch pine stringers 8 feet apart, with 2 inches of sand foundation, cost from $1.04 to $1.20 per square yard, the average being about $1.10. In Michigan, Wisconsin, and Minnesota, 6-inch cedar blocks on 1-inch boards and 1-inch stringers cost from 60 cents to $1.05 per square yard, the range usually being from 75 to 95 cents.

B. RECTANGULAR WOOD-BLOCK PAVEMENT.

858. A pavement composed of parallelopipedons, or "rectangular blocks," was patented by Nicholson in 1848; and for a number of years thereafter this form was in this country generally called Nicholson pavement, and even yet the term is often used. Fig. 144 shows the usual construction. This form of pavement is

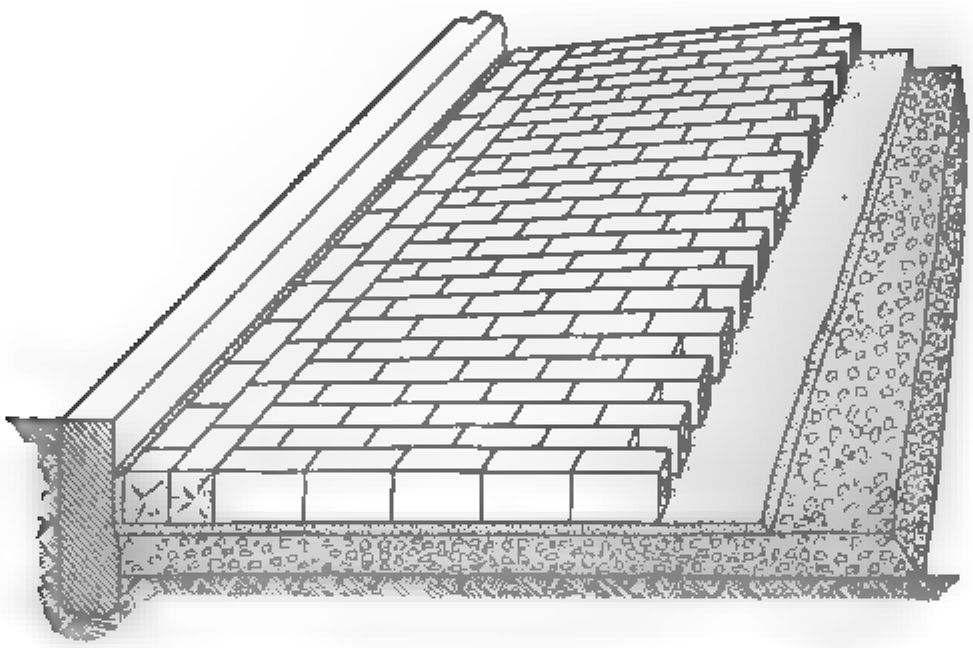

FIG. 144.—RECTANGULAR WOOD-BLOCK PAVEMENT.

now used in this country only to a limited extent. It is the only form of wood pavement in Europe, and is used quite extensively in London and in Paris.

859. FOUNDATION. Rectangular blocks may be laid upon a foundation of sand or upon plank; but in the best practice are laid upon a layer of well-consolidated broken stone or upon a bed of concrete. Concrete is used exclusively in both London and Paris.

In this country a cushion coat of sand is interposed between the concrete and the blocks; but in London and in Paris the concrete, after having been laid quite smooth and level, is floated,—i. e., the surface is coated with a thin layer of lean Portland-cement mortar making a bed for the blocks almost as smooth as the plastered walls of a house.

860. The Blocks. The blocks should be cut from sound timber without wind shakes, knots, or rotten spots, and should be free from sap wood. The faces should be flat, and the corners square. The top and the bottom should be truly parallel, and at right angles to the sides.

861. Apparently the best dimensions for the blocks are: width 3 inches, depth 4 to 6 inches, length 9 inches. Formerly a depth of 6 inches was almost always employed, but it was found that after the blocks had worn down 2 or 3 inches the pavement was so rough and uneven as to require re-laying; and now the blocks are only 4 or 5 inches deep, even under the heaviest traffic. If the pavements are re-laid before the surface becomes very rough, an original depth of 4 inches is enough. This is the depth now generally preferred in London, a city having not only many wood pavements but also the finest wood pavements in the world.

Part of the excellence of the London wood pavements is due to the uniformity of the blocks, the engineers of some of the Vestries not permitting a greater variation either way from the specified width and length than $\frac{1}{16}$ inch. and not permitting any measurable variation in the depth. It is also specified that the corners of the blocks shall be exactly square.

862. Placing the Blocks. The blocks are set with the fiber vertical and the long dimension crosswise of the street. In London the more discriminating engineers specify that the lap shall be one third of the length of the block, a lap which diminishes the tendency for ruts to form in line with the end joints.

Formerly it was believed that the side joints should be left open to afford a foot hold for horses, the first rectangular block pavements in this country being laid with a $\frac{3}{4}$-inch strip between the rows of blocks. Wide joints hasten the destruction of the wood by permitting the fibers to spread under traffic, which also causes the surface of the pavement to wear in small ridges, giving to it a

corduroy effect. The best practice seems to be to lay the blocks on level streets with joints as thin as possible; while on grades of 3 per cent or over, some engineers advocate a ¼-inch joint made as follows: Remove from the top of one side of each block a strip ¼-inch thick and 1½-inches deep for the length of the block. When these blocks are laid as above described, and driven closely together, there is a quarter of an inch opening, or joint, extending clear across the street in each course of block, ¼ inch wide, and 1½ inches deep. These joints are filled with Portland cement mortar. Fig. 145 shows a section of pavement having this form

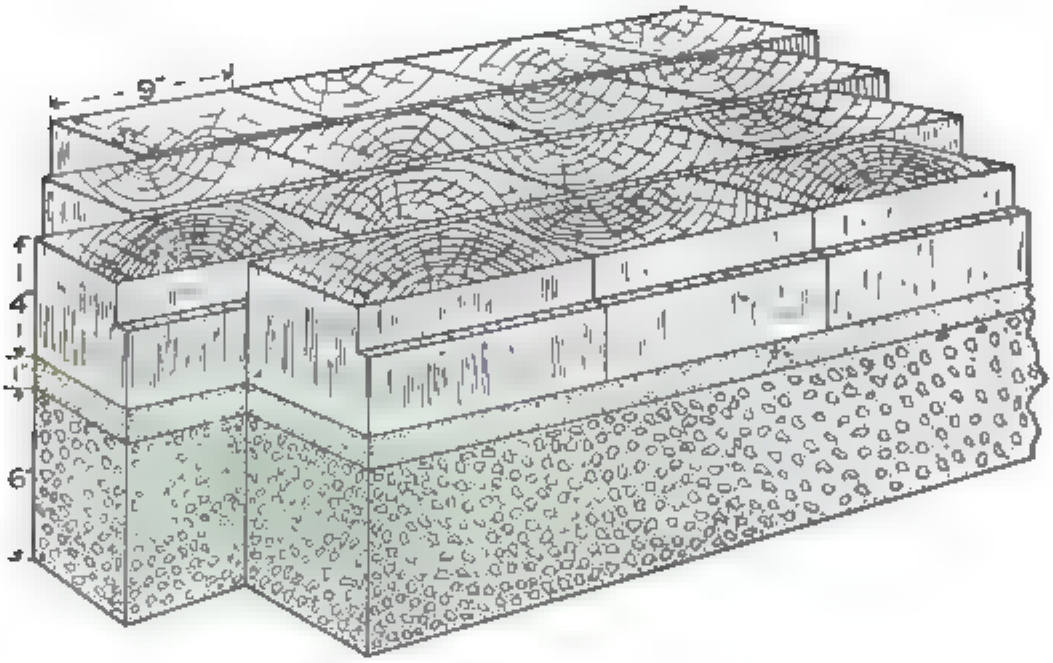

FIG. 145.—RECTANGULAR WOOD BLOCK PAVEMENT WITH WIDE JOINTS.

of joint. Such a pavement was recently laid in Boston on Boylston Street.

863. FILLING THE JOINTS. When the blocks are laid close together, the joints are filled either (1) by sweeping in fine hot sand (§ 774), or (2) by pouring in boiling hot tar or paving pitch (§ 775), or (3) by sweeping in neat Portland cement grout (§ 777). When the blocks are laid with spaces between them, the joints are filled with a 1 to 1 Portland cement grout. Whatever the joint filler, a light coat of fine gravel or paving sand is strewn over the surface, and then the pavement is opened to traffic.

864. EXPANSION. All untreated wood blocks absorb water and expand to a considerable extent, and treated blocks expand appreciably. The average expansion of creosoted and untreated wood

blocks after immersion in water for forty-eight hours is about as follows:

Dimension.	Per Cent of Expansion. Untreated.	Creosoted.
On length of block..................	0.60	0.10
" width " "	0.83	0.57
" depth " "	0.31	0.15

At the above rates, the expansion in the width of a 30-foot pavement would be 2½ inches for untreated blocks and practically ⅜ inch for creosoted blocks, provided the blocks were fully saturated; but the blocks will never be this wet, and therefore the maximum expansion will be considerably less than that stated. If either treated or untreated blocks are laid in contact or with a rigid filler, the expansion due to absorption of water is likely to disturb the curbs or lift the blocks from the foundation. This expansion may be provided for by the same method as that of brick pavements due to heat (see § 786).

In London, expansion is provided for by leaving between the blocks and the curb, a space of 1½ inches which is filled either with clay or with clean, dry sand, coated over with a film of Portland cement mortar. In Chicago pine blocks laid fairly dry and having the joints filled with sand, do not ordinarily expand sufficiently to lift the blocks from the foundation; but oak blocks so laid usually swell sufficiently to heave the pavement.

865. Repairs. The only repairs required, aside from re-placing blocks taken up to get at water and gas pipes, etc., is to remove soft or decayed blocks and to insert new ones. The hole caused by a single decayed block is speedily enlarged by the impact of wheels dropping into the depression. The top face of the new block should not be higher than the general surface of the pavement for a high block is fully as serious a defect as a low one.

It is frequently stated that the average cost of repairs of wood pavements in English and Continental cities is from 1½ to 3 cents per square yard per annum, but such data are not very instructive since nothing is known concerning the nature and the amount of the traffic per unit of width, the details of the construction of the pavement, the climatic conditions, the cause and nature of the repairs, etc.

866. PERMISSIBLE GRADES. Rectangular wood blocks with close joints are used on grades up to 3 or 5 per cent without being seriously slippery. The limit depends upon the climate, the cleanliness of the pavement, and the character of the wood employed. In London and Paris, it is customary to strew coarse sand and small pebbles over the surface of wood pavements to keep them from becoming slippery. The sand grains and the pebbles become imbedded in the wood, are quite effective in preventing the horses from slipping, and add somewhat to the durability of the pavement. In London the limiting grade for wood blocks is usually considered 4 per cent, although Savoy Street, the grade of which is 8 per cent, and Arundel Street, the grade of which is 7 per cent, are paved with wood. On grades greater than 3 to 5 per cent, it is customary to lay the blocks with open joints (§ 862). Sidney, New South Wales, has a rectangular block pavement upon an 8 per cent grade, which gives no serious trouble. Duluth, Minn., uses round blocks on a 10 per cent grade or less, but on steeper grades uses rectangular blocks with $\frac{3}{4}$-inch joints filled with gravel.

867. MERITS AND DEFECTS. The chief merit of a rectangular block pavement is its quietness; and its chief defects are its slipperiness, its lack of durability if not preserved, and its cost if treated.

In this country brick or sheet asphalt has taken the place formerly occupied by wood-block pavement; but in Europe, particularly in London and Paris, when a quiet pavement is desired, the contest is between broken stone on the one hand and rock asphalt on the other.

868. COST. Oregon red-cedar and southern yellow-pine heartwood blocks, 4″ × 4″ × 9″, creosoted with 10 pounds per cubic foot, were laid in 1899 in Indianapolis, Ind., at a cost of $2.10 to $2.50 per square yard, including the concrete base and a five-year guarantee, the joints being filled with paving cement of nine parts of coal tar to one part of asphalt, and the surface being covered with half-inch screenings of crushed granite.

The 5-inch kreodone-creosoted blocks laid in 1901 in front of the Auditorium Hotel on Michigan Avenue, Chicago (§ 847), cost $1.90 a square yard, including a 5-year guarantee but not including the concrete base.

The 4-inch creo-resinated wood-block pavement laid in Boston (§ 848) in 1901 cost from $3.10 to $3.50 a square yard, including a 6-inch concrete foundation and a 10-year guarantee.

869. In London 5-inch jarrah blocks cost from £10 to £11 ($48.40 to $53.20) a thousand, and karri blocks about $1.20 a thousand less; and the pavement complete on an old foundation costs from $2.50 to $3.00 per square yard. The cost of a creosoted-deal pavement on an old foundation varies from $1.50 to $2.00 per square yard.

870. In Paris pine blocks of various kinds, impregnated with 8 to 10 pounds of creosote oil per cubic foot, constitute the greater part of the 90 miles of wood pavements, and cost, including a 6-inch concrete base, about $3.10 per square yard.

CHAPTER XVIII.

COMPARISONS OF PAVEMENTS.

872. Pavements have been constructed of a variety of materials; but the forms discussed in the preceding chapters—asphalt, brick, stone block, and wood block—are the only ones of importance now constructed, and it is improbable that any other paving material of value will be introduced. From time to time notices appear in the general newspapers of the introduction of some new pavement. Among the new paving materials of which notices have recently appeared are compressed hay, devitrified glass, cork, and rubber. All such novelties are either an attempt of an eccentric inventor to sell his goods or a construction to meet limited and peculiar conditions. For example, it has been stated that rubber has been tried as a paving material in London; but the facts are that it has been used only to the extent of 300 or 400 square feet in a hotel porte cochère.

Macadam and gravel were considered in Part I as materials for surfacing country roads, but it will presently be shown that they are employed as a covering material on half or more of the "paved" streets of the cities of the United States;* and therefore macadam and gravel roads must in this chapter be considered as pavements. These materials are entirely unsuitable for streets having a heavy traffic, on account of the surface being speedily ground to powder which makes dust and mud and necessitates frequent repairs which are likely to hinder traffic; but they have some very desirable qualities for purely residence streets and for the main streets of small

* In Table 55, page 564, these two constitute 45 per cent, and in Table 56, page 565, 59 per cent; but if the smaller cities were included the per cent of gravel and macadam pavements would probably be still larger.

towns, and are eminently fitted for pleasure drives in parks and elsewhere.

873. Amount of Different Kinds of Pavements. Table 55 shows the number of miles and also the relative proportion of

TABLE 55.

Number of Miles and Relative Proportion of the Different Kinds of Pavements in One Hundred and Thirty-five American Cities in 1901.*

Ref. No.	Kind of Pavements.	Miles.	Per Cent.
1	Asphalt—sheet and block..........	2 061	13.6
2	Brick	1 186	7.9
3	Cobble Stone	1 034	6.8
4	Granite and Belgian Blocks........	2 020	13.4
5	Gravel	2 225	14.7
6	Macadam	4 615	30.6
7	Wood	1 313	8.7
8	All others.......................	645	4.3
	Total	15 099	100.0

* Compiled from Statistics of Cities, Bulletin No. 36 of U. S. Department of Labor, September 1901, p. 876–79.

the different kinds of pavements in the one hundred and thirty-five cities having a population of 30,000 or over in June, 1901. Notice that the fourth line in the table is "granite and Belgian blocks," and not stone blocks; and therefore sandstone- and limestone-block pavements must be included in line 8, which is unfortunate since sandstone-block pavements have substantially the same qualities as granite-block pavements. The last line of the table under the head of "all others," includes sandstone and limestone block, rubble, shell, tar distillate, granolithic, slag block, and perhaps telford—at least Boston, Buffalo, and St. Louis usually separate macadam and telford pavements in their official reports. There is a considerable extent of sandstone-block pavements, particularly in the Lake Cities. In 1892, Philadelphia reported 115 miles of rubble pavement (§ 807), which was 14 per cent of all the pavements in that city. Some of the Southern cities have rubble pavements, and several others have streets paved with shells.

874. Of the 2,061 miles of asphalt pavements, Philadelphia has 289 miles, Greater New York 264, Buffalo 224, Washington 125, and Chicago 103, these five cities having practically half the asphalt pavements reported in Table 55. Of the 1,186 miles of brick pavements, Philadelphia has 128 miles, more than twice as much as any other city. Of the 1,034 miles of cobble stone, Baltimore has 321 miles and New York 229 miles, the former being 90 per cent of all the pavements in the city and the latter 13 per cent. Of the 2,020 granite- and Belgian-block pavements in Table 55, New York has 459 miles and Philadelphia 358, no other city having more than 88 miles. The milage of macadam pavements in the five largest cities is as follows: New York 766 miles, Chicago 387, Boston 292, St. Louis 259, and Philadelphia 208. Of the 1,313 miles of wood pavement in Table 55, Chicago has 749 miles (58 per cent of all the pavements in the city), and Detroit has 223 (73 per cent of all the pavements in the city), these two cities having 80 per cent of all the wood pavements reported.

875. Table 56 gives the number of miles and relative proportions of the different kinds of pavements in two hundred and sixty-two cities having a population in 1890 of 10,000 or over.

TABLE 56.

NUMBER OF MILES AND RELATIVE PROPORTION OF THE DIFFERENT KINDS OF PAVEMENTS IN TWO HUNDRED AND SIXTY-TWO AMERICAN CITIES IN 1890.*

Ref. No.	Kinds of Pavements.	Miles.	Per Cent.
1	Asphalt—sheet and block	394	3.2
2	Brick	.....	....
3	Cobble Stone	1 888	15.1
4	Stone Block	1 504	12.1
5	Gravel	3 858	31.0
6	Macadam	3 474	27.9
7	Wood	969	7.8
8	All others	366	2.9
	Total	12 453	100.0

* Compiled from Social Statistics of Cities, Eleventh U. S. Census, 1890, p. 15–19.

Table 56 is given in the same form as Table 55 for convenience in making comparisons. Notice that no brick pavements were re-

ported separately in 1890. Notice also that the fourth line of Table 56 is stone block, and not granite and Belgian block as in the corresponding line of Table 55. A comparison of Tables 55 and 56 shows that the per cent of asphalt pavements in eleven years increased more than fourfold; and in the same time the per cent of cobble-stone and of gravel pavements decreased more than half, while that of macadam and of wood slightly increased.

876. Requirements of an Ideal Pavement. The perfect pavement is an ideal which will never be attained, since some of the qualities required in a perfect pavement are antagonistic to each other. For instance, perfect durability would require a pavement without friction, for friction causes wear and ultimately destruction of the pavement; but without friction there could be no adequate foot hold for horses drawing loads. Again, to be the least injurious to horses, a pavement should be soft and yielding; but a soft and yielding pavement is opposed to ease of traction. The conditions to be fulfilled by the ideal pavement will first be considered; and subsequently an attempt will be made to estimate the degree to which each kind of pavement approximates the perfect ideal.

A perfect pavement should satisfy the following conditions:

1. It should be low in first cost.
2. It should be durable, i. e., the cost of perpetually maintaining its surface in good condition should be small.
3. It should have a smooth, hard surface, so as to have a low tractive resistance.
4. It should afford a good foot hold to enable horses to draw heavy loads, and to prevent them from slipping and falling and possibly injuring themselves and blocking traffic.
5. It should be smooth, so as to be easily cleaned.
6. It should be comparatively noiseless.
7. It should be impervious, so as to keep in good sanitary condition.
8. It should yield neither dust nor mud.
9. It should be comfortable to those who ride over it.
10. It should not absorb heat excessively.

Each of the ordinary forms of pavements will be considered under each of the above requirements.

877. Cost. The cost of construction of a pavement varies with the character of the work and with the locality. For data on this subject, see the several kinds of pavements in the preceding chapters.

878. Durability. The durability of a pavement made of perishable material, as wood and to some extent macadam, gravel and asphalt, depends upon both the climate and the traffic; but in general the durability of paving materials depends chiefly upon the volume of the traffic, and consequently the durability of different pavements can be accurately compared only when the nature and the amount of the traffic over each is known. Unfortunately there are very little definite data as to the amount of traffic upon American pavements. Not infrequently the traffic on a particular pavement is referred to as being "heavy" or "light," but such general terms are practically worthless in comparing the durability of different kinds of pavements. Only a few detailed observations have been made concerning the traffic upon American pavements, and they are somewhat antiquated.

879. *Traffic Census.* The first and the most elaborate census of street traffic taken in this country was made in 1885 under the direction of Capt. F. V. Greene. Table 57, page 568, gives a summary of the results, and the following extracts from Captain Greene's article * explain the details of the method of making the observations.

"The observations were made during the months of October and November, 1885, by the employees of the Barber Asphalt Paving Company, which has an office and works in the ten large cities. In the arrangements for taking the observations two objects were kept in view: first, to leave as little as possible to the judgment of the observer; and second, to make the record permanent, so that it could be preserved for examination in all its details at any time.

"The agent in each city was instructed to select the three streets in that city paved with stone, asphalt, and wood (if any existed) which, by common report, had the heaviest traffic on the class of pavement used on that street. The record was in

* Trans. Amer. Soc. Civil Eng'rs, Vol. 15, p. 123–38.

TABLE 57.

Traffic on Certain Streets in Various American Cities in 1885.

Ref. No.	Locality.		Width of Pavement, in Feet.	Number of Tons.		
	City.	Street.		Total per Day.	Per Vehicle.	Per Foot of Width per Day.
1	New York..	Broadway, near Pine..........	40	10 905	1.39	273
2	" " ..	Fifth Ave., opp Worth Monum't	40	3 744	.68	94
3	" " ..	Wall, corner of Broad.........	27	2 357	1.00	87
4	Philadelphia	Broad, in front of P.R.R. Depot	65	9 237	1.52	142
5	"	Filbert, in front of City Hall ...	65	6 302	1.24	97
6	"	Chestnut, corner of Fourth.....	26	1 928	1.06	74
7	Chicago	Wabash, near Lake............	50	7 561	2.08	151
8	"	Clark, near Madison...........	45	6 398	1.46	142
9	"	La Salle, near Locust..........	36	2 756	.90	77
10	"	Dearborn, opp. Washington P'k	38	2 604	1.11	69
11	Boston	Devonshire, opp. Post Office....	27	5 301	.99	196
12	"	Devonshire, near Milk.........	32	5 028	1.02	157
13	"	Kilby, near State.............	26	3 265	.93	126
14	"	Washington..................	39	2 938	.80	75
15	"	Arch, near Summer...........	26	1 130	.79	43
16	"	Court Square................	24	744	.67	32
17	St. Louis ...	Locust, near Beaumont........	36	3 691	1.13	103
18	" " ...	Broadway, near Olive.........	50	3 618	1.23	72
19	" " ...	Pine, near Garrison...........	36	2 554	1.16	70
20	" " ...	Chestnut, near Beaumont......	36	942	.90	27
21	" " ...	Olive, near Beaumont.........	36	259	.84	7
22	New Orleans	Tchoupitoulas, near Poydras....	40	6 204	1.81	155
23	" "	St. Charles, near Washington...	30	1 065	.94	35
24	Washington.	15th, opposite Treasury........	70	4 622	1.02	66
25	"	9th, between D and E.........	50	1 688	.87	34
26	"	7th, between D and E.........	50	1 445	.88	29
27	"	6th, between Pa. Ave. and B...	60	1 289	1.01	21
28	Buffalo......	Main, near Swan..............	56	2 613	.83	47
29	"	Main, near Bouck Ave.........	42	1 505	1.88	36
30	"	Linwood, near Ferry...........	38	825	1.47	22
31	"	Main, near Glenwood..........	50	714	1.24	14
32	Louisville...	Main, near 3d.................	61	4 176	1.25	69
33	" ...	8th, near Walnut..............	36	2 402	1.05	67
34	" ...	7th, near Jefferson............	35	977	1.05	28
35	Omaha	Douglass, near 15th...........	63	2 967	.62	47
36	"	Farnham, near 14th...........	60	1 449	.59	24

every case made on six consecutive days (Sunday excepted) at the same place, and it was continuous from 7 a. m. to 7 p. m., except when darkness prevented. No addition was made for this omission, no record was kept during the night, and no addition was made as an estimate of night traffic.

"The printed instructions issued to each observer contained the following rules as a guide in estimating the weights of vehicles:

" '1-horse carriages, empty or loaded, 1-horse wagons, empty or light-loaded, 1-horse carts, empty,	Less than 1 ton.
1-horse wagons, heavy-loaded, 1-horse carts, loaded, 2-horse wagons, empty or light-loaded,	Between 1 and 3 tons
Wagons and trucks drawn by two or more horses, heavy-loaded,	Over three tons.

Special note will be made, in the column of remarks, of any unusually heavy loads, such as 6-horse trucks loaded with stone or iron, and an estimate be given of their weight.'

"The traffic is divided into three classes, light weight (less than one ton), medium weight (between one and three tons), and heavy weight (more than three tons); and in order to reduce the personal equation of the different observers to a minimum, the directions specify what classes of vehicles are to be counted in each class of weight. Nothing is then left to the observer's judgment and estimation except the question of 'heavy' and 'light' loads in one-horse and two-horse wagons. The result of different estimation in this respect between two observers would simply change a portion of the vehicles from one class to another, and the error in the final result could hardly exceed 5 per cent.

"The weight of the horses is discarded altogether, not because they do not constitute a factor in the wear of the pavement, but because they were discarded in the English reports, and it was desired as far as possible to make comparisons with them. The addition that would have to be made if the horses were included would vary with the traffic. On streets where light vehicles predominate (as on Fifth Avenue, New York), the addition to the tonnage by including the weight of the horses would be about 85 per cent; on streets with heavy vehicles (such as Wabash Avenue,

Chicago), it would be only about 40 per cent; and for other streets it would be between these two limits.

"The average daily traffic was obtained by dividing the total record for six days by six. To obtain the tonnage, the light-weight vehicles were estimated to average one half ton each (including their loads), the medium-weight two tons, and the heavy-weight four tons. Multiplying the daily average of vehicles in each class by these figures and adding together the products, the total tonnage was obtained; and dividing this by the width between curbs, we get the daily average tonnage per foot of width.

"The average tonnage per vehicle is an almost infallible indicator of the character of the street, i. e., whether devoted to residential or business purposes. It ranges from 0.68 tons on Fifth Avenue in New York to 2.08 on a portion of Wabash Avenue in Chicago. The same character is indicated by the proportions of light and heavy vehicles on the street. On Fifth Avenue, for instance, 91 per cent of all the vehicles weigh less than one ton, while on Wabash Avenue only 25 per cent of them have so little weight. The general average for all the cities is as follows: less than one ton, 67 per cent, between one and three tons, 26 per cent; more than three tons, 7 per cent."

880 During the years 1888 and 1889 the Warren-Scharf Asphalt Paving Co.* made observations on twenty-five streets in ten cities on seven kinds of pavements, the length of the observations for a particular street varying from one to seven days. In these observations the tonnage, including both horses and vehicles, varied from 6 to 138 tons per day per foot of width of pavement.

In 1892 the Board of Public Works of Indianapolis, Ind., took a traffic census of thirteen of the principal streets of that city, the observations being made according to the system employed by Captain Greene (§ 879).† The traffic varied from 16 to 110 tons per day per foot of width of pavement.

In 1892 a census of traffic was taken on twenty-five streets of Montreal, Canada.‡ The method was the same as that em-

* Advertising pamphlet published by the company.

† Paving and Municipal Engineering (now Municipal Engineering), Vol. 3, p. 68–69.

‡ Annual Report of City Engineer for 1893, p. 295–319.

ployed by Captain Greene (§ 879) except that the observations were made from 7 a.m. to 6 p.m., and except further that the weight of the horses was included, the weight of each being estimated at half a ton. The tonnage varied from 17 to 146 tons per day per foot of width.

The City Engineer's Report of Toronto, Canada, for 1894 contains the details of a traffic census upon three streets in that city made according to Greene's method, except that the weight of the horses was estimated at half a ton each and was included. The tonnage varied from 32 to 79 tons per day per foot of width.

881. Table 58 gives the traffic record of certain streets in London and Liverpool.* The observations were not all made

TABLE 58.

TRAFFIC ON CERTAIN STREETS IN LONDON AND LIVERPOOL.

Ref. No.	Locality.		Pavement.		Number of Tons.		
	City.	Street.	Kind.	Width in Feet.	Per Day.	Per Vehicle.	Per Foot of Width per Day.
1	London	Gracechurch	Asphalt	32	13 507	1.11	422
2	"	King William.....	Wood	40	16 484	1.06	412
3	"	Poultry	Asphalt	22	8 330	1.02	378
4	"	Strand and Fleet..	Wood	37	13 596	.84	367
5	"	Parliament	Macadam	45	14 380	1.01	322
6	"	Oxford	Wood	57	17 076	1.01	300
7	"	Cheapside	Asphalt	32	9 260	.98	290
8	"	Leadenhall	"	30	7 588	1.08	253
9	"	Piccadilly	Macadam	37	9 358	.87	253
10	"	Euston	Granite	44	10 658	.88	242
11	"	Brompton	Wood	....	....	......	216
12	"	King William....	Granite	32	6 506	1.02	203
13	"	Edgeware	"	43	8 376	1.02	195
14	"	Regent	Macadam	52	9 668	.90	186
15	"	King's	Wood	....	....	......	156
16	"	Victoria	Macadam	40	5 780	.96	145
17	"	Sloane	Wood	....	....	......	93
18	Liverpool...	(Not named).....	Granite	....	....	......	382
19	" ...	" "	"	....	....	......	232
20	" ...	Great Howard....	Wood	....	....	......	231
21	" ...	Bold	"	....	....	......	100

* Trans. Amer. Soc. of Civil Eng'rs. Vol. 15, p. 131.

under the same direction, but not much is known concerning the methods employed. Some of the observations were made from 8 a. m. to 8 p. m., and some from 7 a. m. to 11 p. m.

In Paris it is customary to state the traffic in number of "collars" per unit of width, no tonnage being given.

882. It is desirable that engineers in charge of streets and roads should ascertain by direct observation the amount of tonnage passing over each particular pavement, in order that the service per unit of cost of different pavements may be accurately compared. The only measure of the durability of a pavement is the amount of traffic tonnage it will bear before it becomes so worn that the cost of replacing it is less than the expense incurred by its use.

Notice that some of the above results include only vehicular traffic and others include both vehicles and horses. No systematic observations have ever been made to determine the relative destructiveness of horses and vehicles; but apparently, compared ton for ton, horses are more destructive than vehicles. The sharp blows of horses' shoes, particularly if they have heel and toe calks, are very destructive to stone-block and brick pavements, as they spall off the edges of the blocks.

883. *Modifying Elements.* Although the effect of traffic is dependent chiefly upon the number of tons per foot of width, its influence is modified somewhat by (1) the character of the pavement, (2) the state of repairs, (3) the degree of cleanliness, (4) the presence or absence of car tracks, (5) the width of pavement, (6) the character of the traffic, and (7) the climate.

1. The durability of a particular kind of pavement will vary with the details of the method of construction. The foundation may be more or less rigid, the materials may differ greatly in durability, with any form of block pavement the joints may be more or less open, and the surface may also vary more or less in roughness.

2. The durability will depend upon the care employed n repairing the pavement. If holes, depressions, or ruts are allowed to remain for any length of time, whatever the material the pavement will wear abnormally fast.

3. The degree of cleanness will materially modify the durability

of a pavement. An imperishable material is benefited by a covering of detritus, since it serves as a carpet to protect the pavement; and if the covering is heavy enough the pavement virtually becomes a foundation and is entirely protected from wear. On the other hand, the decay of a perishable material, as wood and asphalt, is hastened by a covering of street dirt which collects moisture and hastens the decay and disintegration of the pavement.

4. The presence of a street-car track on a street concentrates traffic at the two sides, thus virtually narrowing the street, and also causes the traffic to go substantially in one track, a result which is particularly destructive of gravel and macadam roads.

5. The wider a pavement the more evenly will it wear, and consequently the longer it will last. If several irregular lines of travel can be maintained, the wear will be much more even and the durability greater than if the vehicles are restricted to practically a single line.

6. The durability of the pavement will vary with the weight per unit width of tire, the method of shoeing the horses, and the rapidity of the traffic. In Europe, the weight per unit of width of tire is generally regulated by law, and calks on the horses' shoes are prohibited; but in America there are no such restrictions. Rapid traffic is more destructive to a block pavement than slow traffic.

7. The climate affects the durability of several kinds of pavement. The durability of a wood pavement is affected by the heat and the moisture conditions, that of macadam and gravel by moisture and winds, and that of asphalt by moisture, particularly by street sprinkling. Sprinkling materially affects the durability of wood pavement, as is shown where a strip is ordinarily left unsprinkled for a foot-way.

884. *Comparative Durability.* Until more complete data concerning the volume of traffic on pavements and the amount of wear are obtained, it will be impossible to make any reliable estimates as to the durability of different paving materials.

It is generally conceded that granite block is the most durable paving material, especially under very heavy loads.

Asphalt and brick rank next to granite, and when well constructed give excellent service except perhaps under the very

heaviest traffic; although it should be noted that as the method of preparing and laying these materials becomes better understood, they are being laid under heavier and heavier traffic. For example, within the last year or two artificial sheet asphalt has replaced granite block on Broadway in the most congested district of New York city—a street probably having the most traffic of any in this country (see Table 57, page 568). Again, only a few years ago it was considered that bricks were suitable only for small cities; but now Philadelphia, the third largest city on this continent, has 128 miles of brick pavements. The production of granite paving blocks has decreased one half in the past ten years, apparently because of the introduction of asphalt and brick pavements. The relative durability of brick and asphalt is a matter of doubt, both materials showing varying results due to differences in the quality of the material and to the method of construction. The following examples show the possible durability of these two materials. A brick pavement on concrete with cement-filled joints laid on one of the principal business streets in Terre Haute, Ind., after eleven years' service without repairs, showed a maximum general wear of only $\frac{1}{32}$ to $\frac{1}{16}$ of an inch with a few holes showing a wear of $\frac{1}{8}$ of an inch, the population of the city increasing in the meantime from 30,000 to 36,600 and there being a double track car-line on the street. An asphaltic limestone pavement on Cheapside, London, which has a daily traffic of 290 tons per foot of width (see Table 58, page 571), wore down about 1 inch in seventeen years. It is said that the average life of asphaltic limestone pavements in London and Paris is about seventeen years. An artificial sheet asphalt pavement on Pennsylvania Avenue, Washington, D. C., was re-laid after thirteen years' use. The method of repairing asphalt pavements, both artificial and natural rock, may, however, make such examples as the last two misleading. For data on cost of maintenance of asphalt pavements, see § 670–74.

Round-block soft-wood pavements are lacking in durability, but rectangular blocks of both soft and hard wood have given satisfactory service under heavy traffic in London and Paris. For example, at the end of Westminster Bridge, where the traffic from 6 a. m. to 6 p. m. is 334 tons per foot of width, of which 15 per cent is heavy omnibuses, the mean of six years' wear of jarrah rectangu-

lar blocks was 0.16 inch per year.* On Euston Road, London, where the traffic not including horses was 529 tons per 24 hours per foot of width, of which 7.7 per cent was heavy omnibuses, the maximum wear of the jarrah and karri rectangular blocks was 0.08 of an inch per annum and yellow deal 0.46 of an inch.† At another place on Euston Road, where the traffic, not including horses, was 381 tons per 24 hours per foot of width, the maximum wear of jarrah blocks was $\frac{5}{16}$ of an inch, the minimum being $\frac{3}{16}$ of an inch, and the average $\frac{1}{4}$ inch.‡

Broken stone and gravel wear rapidly under moderately heavy traffic, and are suitable only for residence and suburban streets, and for park roads and pleasure drives.

885. In trying to determine the probable life of a pavement, two facts should not be overlooked, viz., (1) The average wear does not determine the life of a pavement, since even the most carefully constructed pavements wear so unevenly as to require re-laying before the wearing coat is entirely worn out. This is true of macadam and sheet asphalt which have a comparatively thin wearing coat, and is particularly true of pavements made of blocks, as wood, brick, and stone, since the edges of the blocks wear off and leave the top face rounded, and when the pavement reaches this stage the wear is much more rapid than previously. (2) In a block pavement the blocks must have a certain depth to enable them to keep their place, and consequently bricks and shallow wood blocks can not be worn more than about half-way through. If the blocks are made deeper, the durability of the pavement is not increased much, if any, since owing to unequal wear the pavement must be re-laid before any considerable depth is worn off. Asphalt and trap-topped macadam have some decided economic advantages over other forms of pavements, since the wearing surface consists of a comparatively thin wearing coat that can be replaced when it is worn out or wears rough, without proportionally as much loss as when a block pavement is re-surfaced. A further

* J. F. Norrington, Surveyor of Lambeth, Proc. Assoc. Municipal and County Engineers, Vol. 22, p. 93.

† W N. Blair, Assoc. M. Inst. C. E., Engineer St. Pancras Vestry, Proc. Assoc. Municipal and County Engineers, Vol. 22, p. 86–87.

‡ *Ibid.*, p. 89.

economic advantage of these pavements is that when holes begin to form a patch can be applied and thus the uniformity of the surface may be preserved and the life of the pavement be extended. Trap-topped macadam has an economic advantage over asphalt, in that when it is re-surfaced the old material is not thrown away but is simply picked loose and mixed with the new stone.

886. Tractive Resistance. Table 9, page 31, gives the tractive resistance of different pavements, from which it is seen that the rank of the various pavements according to tractive resistance, in order beginning with the one offering the least resistance, is about as follows: Asphalt during cold weather, brick, best macadam, asphalt during warm weather, rectangular wood block, good gravel, new cylindrical wood block, carefully dressed stone block, ordinary macadam, ordinary gravel, ordinary stone block, old cylindrical wood block, cobble stone. The tractive resistance will vary greatly with the state of repair of the surface.

Many attempts have been made to compute the financial advantage of a decreased tractive resistance, but it is impossible to determine its value with any degree of accuracy, although it is certain that the tractive resistance of the pavements of a city are important factors in determining the cost of conducting transportation. Ease of traction is, however, not relatively as important for city pavements as for country roads, since in the latter ease of traction is a matter of first importance (see § 4–9), while in the former it is comparatively unimportant (see § 442). On the other hand, the cost of transportation per ton-mile is considerably more in the cities than in the country.

887. Slipperiness. The method of comparing pavements in this respect is to determine the distance a horse travels on the different pavements before he falls. The most complete observations made in the United States to ascertain the prevalence of accidents on the different pavements were made under the direction of Capt. F. V. Greene.* The observations were made from 7 a.m. to 7 p.m. on six consecutive days in October and November, 1885, in ten of the leading American cities on thirty-three streets having the heaviest traffic for each kind of pavement in

* Trans. Amer. Soc. of Civil Engineers, Vol. 15, p. 123-28.

the particular city. The number of horses observed on asphalt pavements were 360,254, on granite 376,384, and on wood 70,914; and the number of miles traveled by the horses while under observation was 41,427 on the asphalt pavements, 34,723 on the granite, and 4,901 on the wood. A summary of the results is shown in Table 59.

TABLE 59.

MILES TRAVELED BY A HORSE ON AMERICAN PAVEMENTS BEFORE AN ACCIDENT OCCURS.

Ref. No.	Kind of Pavement.	Fall on Knees.	Fall on Haunches.	Complete Fall.	Accident of Any Kind.
1	Asphalt, artificial sheet.......	1 534	2 180	1 647	583
2	Granite Block................	510	5 954	3 472	413
3	Wood *......................	408	983	4 901	272

888. An elaborate series of observations was made in London in 1873 by Col. William Haywood.† The three classes of pavements, asphalt, granite, and wood, were observed as nearly as possible under the same conditions of space, weather, gradients, etc., on fifty different days. The results are shown in Table 60.

TABLE 60.

MILES TRAVELED BY A HORSE ON LONDON PAVEMENTS BEFORE AN ACCIDENT OCCURS.

Ref. No.	Kind of Pavement.	Dry Weather.	Damp Weather.	Wet Weather.
1	Asphaltic Limestone........	223	125	192
2	Granite Block	78	168	537
3	Rectangular Wood Block....	646	193	432

* The kind of wood block is not stated, and apparently it can not now be determined.

† Report to the Honorable the Commissioners of Sewers of the City of London on the Accidents to Horses on Carriageway Pavements. By William Haywood, Engineer and Surveyor to the Commission. London, 1873. Published also on pages 297–317 of Streets and Highways in Foreign Cities, Vol. III of Special Consular Reports, Washington, 1891.

The average distance traveled by a horse before an accident occurred was as follows:

On Asphaltic Limestone	191 miles
On Granite Block	132 "
On Rectangular Wood Block	330 "

As a result of the above observations, the following conclusions were drawn. "Slight rain makes asphalt and wood more slippery than they are at other times. On asphalt the slipperiness begins almost immediately after the rain commences, while wood requires more rain before its worst condition ensues. The slipperiness lasts longer upon wood, on account of its absorbent nature, than it does upon the asphalt. When dry weather comes after the rain, asphalt is in its most slippery condition and horses fall upon it very suddenly. Wood is frequently in that peculiar condition of surface in which horses slip or slide along without falling. A small quantity of dirt on asphalt makes it very slippery. In damp weather granite blocks become very greasy and slippery; in dry weather, if they are of a hard variety, the surface polishes and becomes rounded and the only foot hold is by the joints between the blocks."

889. The difference in the results for slipperiness of pavements in London and in American cities may be due in the case of the wood and the stone pavements to climatic causes. London is more damp and foggy than any one of the American cities in which the traffic was observed, and therefore its pavements would be more slippery. The difference in the case of asphalt may be accounted for by the difference in the character of the material. The asphalt pavements in London are made from asphaltic limestone, which makes a very smooth, hard surface; while the American pavements are made from natural bitumen mixed with sand, which forms a rough, granular surface. Further, in London, and generally in Europe, the horses' shoes have no calks, and therefore they will slip more than in America where shoes with calks are the rule.

The slipperiness of a pavement varies greatly with the degree of its cleanliness. The slipperiness of an asphalt pavement can be decreased by sprinkling coarse sand over the surface, and the slipperiness of wood can be greatly decreased by strew-

ing small pebbles over it, both of which remedies are frequently used in London and Paris.

890. No observations similar to the preceding have been made for brick pavements, but it is probable that they are less slippery than asphalt, wood, or stone block. Macadam and gravel are the least slippery of any of the pavements under consideration.

891. Ease of Cleaning. The facility with which a pavement may be cleaned is an important matter both economically and esthetically. Col. Geo. E. Waring, noted for his service as Street Cleaning Commissioner of New York city, in 1896 estimated that if all the streets of New York city were paved with asphalt where the grades would permit, the cost of street cleaning would be reduced from $1,200,000 to $700,000 per year. At that time New York had 431 miles of pavement of which 94 were asphalt, and the above annual saving is equal to 3 per cent of the cost of laying asphalt pavements upon all of the streets not already asphalted.

Sheet asphalt pavements are most easily cleaned, and next in order are: asphalt blocks, wood blocks with close joints, brick with joints filled with tar or hydraulic cement, stone block with tar or cement joints, ordinary stone block, round wood block, cobble stone.

Macadam and gravel are smooth and for this reason are easily cleaned; but their surfaces grind up into powder, particularly under dense or heavy traffic, and for this reason there is considerable detritus to be removed, a fact which adds to the expense of cleaning.

892. Noiselessness. The noise made by traffic upon a pavement has an important effect upon the comfort and health of the people using the pavement or living adjacent to it. A quiet pavement is particularly desirable adjacent to office buildings, schools, churches, hospitals, etc.; and the noise of traffic upon a rough pavement aggravates, if it does not cause, nervous disorders.

On sheet asphalt the only noise is the sharp click of the horses' shoes; and on asphalt block there is the click of the feet and a slight rumbling of the wheels over the joints, particularly if the blocks were not laid very close together. Horses' feet make considerable noise on all brick pavements, and wheels

produce a decided roar on pavements made of bricks or blocks having rounded corners, at least while the pavements are comparatively new; but if the bricks have square edges and the joints are filled with tar or hydraulic cement, there is only a little rumbling. Stone-block pavements are the most objectionable in this respect, producing a continual roar due both to the rumbling of the wheels and to the blows of the horses' shoes. Upon wood pavements the horses' feet produce no noticeable noise; while the wheels make a dull rumbling noise, but not loud enough to be seriously objectionable. Macadam and gravel are more quiet than wood.

In order of their noise, pavements rank about as follows: stone block, brick, asphalt, wood, gravel, macadam.

893. Healthfulness. The effect of a pavement upon the health of the residents in its locality will depend upon the tendency of the materials composing it to decay and also upon its permeability. Wood is the only paving material that is subject to decay, and is also the only material that is in itself permeable. The gradual decay of the wood is not in itself a serious menace to health; but the decaying wood makes a lodging place for filth and disease germs. The permeability of any wood block is small as compared with that of the wide joints of round wood-blocks and of ordinary stone blocks, and it has never been claimed that the ordinary stone-block pavement with its wide and permeable joints was specially unhealthy. It has not been proved that wood pavements appreciably affect the health of a community.

Continuous sheet pavements are best in sanitary qualities, although block pavements having joints filled with tar or hydraulic cement are not seriously objectionable.

894. Freedom from Dust and Mud. The materials of an ideal pavement should not grind up and make dust in dry weather or mud in wet weather. The dust and mud not only add to the expense of cleaning the pavement, but are a discomfort to those who use the pavement and to those who live or do business adjacent to it.

895. Comfort in Use. If the pavement is to be used for pleasure driving, the comfort of the users must be considered;

and therefore the pavement should have a smooth surface which is free from dust when it is dry and from mud when it is wet.

896. Temperature of Pavements. During hot weather, there is frequently complaint that one pavement reflects or radiates more heat than another. Observations made in Washington, D. C., when the temperature of the air 2 feet above the pavement was 104° F., showed the temperature of three pavements to be as follows: artificial sheet asphalt 140°, asphalt block 122°, and macadam 118°.* Observations in Boston, when the temperature of the air in the shade was 98° F., gave the temperature of four pavements as follows: wood block 124½°, granite block 115°, sheet asphalt 113°, and macadam 102½°. The observations are not conclusive as to the relative temperatures of different pavements, but show that there is no very great difference between the several kinds. The temperature of the pavement depends upon its color, which varies with the material.

897. Selecting the Best Pavement. The problem of selecting the best pavement for any particular case is a local one, not only for each city but also for each of the various parts into which the city is imperceptibly divided, and it involves so many elements that the nicest balancing of the relative values for each kind of pavement is required to arrive at a correct conclusion.

In some localities, the proximity of one or more paving materials determines the character of the pavement, while in other cases it may require a careful investigation to select the most suitable material. Local conditions should always be considered, and hence it is not possible to lay down any fixed rule as to what material makes the best pavement; but a careful study of the requirements of the ideal pavement and of the qualities of the different kinds of pavements will promote an intelligent selection in any particular case. The decision must always be largely a matter of judgment; but the engineer should reach his conclusion by a series of carefully considered steps, and not by a single hap-hazard leap. He should weigh

* Proc. Amer. Soc. Municipal Improvements, Vol. 5, p. 161.

all the evidence and not base a decision upon a single item, as is too often the case; nor should he adopt the practice of some other locality without a careful consideration of the local resources and of the needs of the place in which the pavement is to be laid, as is frequently done.

898. Relative Merits. It is proposed to compare different kinds of pavements by assigning percentages to the different qualities of an ideal pavement, and then with this as a guide to assign numerical values to the various qualities of the several kinds of pavements.

The various qualities of a perfect pavement have been discussed in § 877 to § 896, and these qualities have been grouped in Table 61, page 583, under the three heads: (1) economic qualities, (2) sanitary qualities, and (3) acceptability. Opposite each of these qualities in the first column of Table 61 is placed a number which is believed to represent the average relative importance of that particular quality on a scale of 100.

The assignment of these numbers is wholly a matter of judgment, and different individuals will differ greatly as to the relative values to be given to each quality; but the table is only to show a method whereby the good and the bad qualities of one kind of pavement may be balanced against those of another kind, and a conclusion may be reached step by step, which represents the algebraic sum of the judgment on each item.

Different values should be assigned to the same quality according to the attendant conditions. If the street is in a manufacturing district and subject to heavy traffic, ease of traction should be assigned a comparatively high value, and noise a very low value. For an office district, quietness is the controlling factor, and should therefore have a relatively high value. Similarly, for a residence district with its light driving, healthfulness and freedom from dirt and dust may be the most important element; for a residence district where the property owners can not afford an expensive pavement, the first cost may determine the kind of pavement; and on a steep grade slipperiness may out-weigh all other conditions in determining the kind of pavement to be employed. The application of these principles is likely to be complicated by the personal interests of the residents or property holders, since opinions

TABLE 61.

RELATIVE VALUES OF THE DIFFERENT QUALITIES OF VARIOUS PAVEMENTS.

Ref. No.	Qualities.	Percentage Assigned to the Quality.						
		Ideal Pavement.	Sheet Asphalt.	Brick on Concrete.	Gravel.	Macadam.	Granite Block on Concrete.	Rectangular Wood Block.
	Economic Qualities:							
1	Low first cost	15	6	9	15	10	3	8
2	Low cost of maintenance	20	16	14	6	8	20	12
3	Ease of traction	10	10	8	5	6	3	7
4	Good foot hold	5	2	4	5	5	3	1
5	Ease of cleaning	10	10	9	1	3	6	9
	Total	60	44	44	32	32	35	37
	Sanitary Qualities:							
6	Noiselessness	15	10	7	15	15	2	13
7	Healthfulness	10	10	8	6	6	7	5
	Total	25	20	15	21	21	9	18
	Acceptability:							
8	Free from dust and mud	10	10	9	1	3	8	7
9	Comfortable to use	3	2	1	3	3	0	2
10	Non-absorbent of heat	2	1	1	2	2	1	1
	Total	15	13	11	6	8	9	10
	Grand total	100	77	70	59	61	53	65

are likely to differ according to whether the point of view is that of a tenant, a resident property-holder or a non-resident property-holder.

899. Each quality of a pavement will now be considered, and the degree of perfection of this quality possessed by each kind of pavement will be indicated by a numerical value.

900. Importance of First Cost. Since the cost of a pavement varies greatly with local conditions, it is not possible to state a general value for the cost of each kind; but for the sake of illustration, the values in the exhibit below will be assumed, which values are believed to be roughly approximate averages for the best of each kind of pavement.

Kinds of Pavement.	Cost per Sq. Yd.	Relative Weight.
Gravel	$0.50	15
Macadam	0.75	10
Brick	1.75	9
Rectangular Wood Block	2.00	8
Sheet Asphalt	2.75	6
Granite Block	3.50	3

The last column of the above exhibit shows the relative weights assigned to the quality of cheapness. Since gravel is the lowest in first cost, it possesses the quality of cheapness in the highest degree; and consequently it is given a weight of 15—the value assigned to the ideal pavement in Table 61. The weights assigned to this quality decrease from gravel, the cheapest, to granite block, the most expensive. The several weights assigned above to low first cost are entered opposite this quality in Table 61.

901. The first cost of a pavement not infrequently has undue weight in comparing the relative merits of different kinds of pavements. In this connection the fact should not be overlooked that all the other expenses connected with a pavement—cost of maintaining and cleaning it, of conducting transportation over it, of wear and tear on vehicles and horses—is a continuing expense, while the cost of construction is incurred once for all; and therefore in comparing the economic value of pavements, it is only the annual interest on the cost of construction that should be considered in connection with the other items of annual expense. The pavement which costs the most to construct is not always the most expensive, nor is the one lowest in the first cost always the cheapest in the end. The pavement which is truly the cheapest is the one which gives the most profitable returns in proportion to the amount which is expended upon it, as will be shown under Cost of Maintenance in § 902.

A pavement is sometimes selected because of its low first cost, for other than economic reasons. Often the cost of construction is charged against the abutting property, while maintenance is paid for by the whole city; and the result is that many property owners prefer a cheap pavement because they must pay for it, notwithstanding the fact that the cheaper

pavement may cost more for maintenance and be dearer in the long run. Again, the property holders are sometimes really unable to pay for the most economical pavement, and hence a pavement low in first cost is selected as a temporary expedient.

902. Importance of Annual Cost. Since there are no accurate data concerning the volume of traffic and the wear of pavements, and since only a few cities keep account of the amount spent upon a particular pavement or even upon a particular kind of pavements, it is impossible to make any reliable comparisons of the cost of maintenance of different pavements. With the present state of our knowledge, all that can be done is to make an estimate of the life of the pavement under the particular traffic, and then deduce the annual cost, which includes the interest upon the first cost and the expenditures for repairs including periodical renewals. See § 885.

Table 62 shows the estimate of the annual cost of several kinds of pavements for Minneapolis, Minn.* The computations are made for a term of 20 years for a street having an estimated daily traffic of 150 tons per foot of width. The original table did not contain the last column, which is here added by obvious computations.

TABLE 62.

ESTIMATED ANNUAL COST OF VARIOUS PAVEMENTS IN MINNEAPOLIS, MINN.

Ref. No.	Kind of Pavement.	Cost of Construction per Sq. Yd.	Cost of Renewals per Sq. Yd.	Estimated Life Years.	Value of the Pavement at the End of 20 Years, per Sq. Yd.	Total Cost of the Pavement per Sq. Yd. per Year.	Cost of Maintenance per Sq. Yd. per Year.
1	Cedar, 2-inch plank foundation without tar	$0.85	$0.79	6	⅔ of $0.79 = $0.53	$0.22	$0.18
2	" concrete foundation with tar	1.45	.74	8	½ of $0.74 + concrete = $1.04	.25	.18
3	Granite	1.88	1.88	20	$0.60	.22	.13
4	Asphalt Trinidad Lake	2.75	....	...	2.00	.32	.18
5	Brick small size Minnesota	1.80	1.13	10	.80	.29	.20
6	" large size Minnesota	1.90	1.23	10	.80	.31	.21
7	" from Galesburg † Ill.	2.15	1.48	10	.80	.36	.25
8	" from Ohio‡	2.70	2.03	10	.80	.48	.34

* Annual Report of City Engineer F. W. Cappelen for 1893, p. 19.

† Kept in repair for ten years, after which add eight cents per yard per year

‡ All-rail rate for freight.

903. Table 63 gives similar results for pavements in Chicago, by a paving expert.* Interest in this example is computed at 6 per cent.

TABLE 63.

ESTIMATED ANNUAL COST OF VARIOUS PAVEMENTS IN CHICAGO, ILL.

Ref. No.	Kinds of Pavement.	Cost of Construction per Sq. Yd.	Cost of Renewals per Sq. Yd.	Life of Pavement Under Different Classes of Traffic, in Years.			Annual Cost of Maintenance for a Term of 50 Years, per Sq. Yd.		
				Light.	Medium.	Heavy.	Light.	Medium.	Heavy.
1	Cedar block on 2-inch plank	$1 00	$0 90	10	7	..	$0.22	$0.33	...
2	" " " 6" of rubble	1 25	0.80	12	8	..	0 20	0 28	...
3	" " " 9" " "	1.40	0 80		9	4		0.28	0.53
4	" " " 6" " concrete	1.40	0.80	12	9		0.20	0 28	
5	" " " 9" " "	1.65	0.80		10	5	...	0.28	0.46
6	Brick, 1 course on 6" of rubble	1.45	1 15	30	15		0.14	0.24	
7	" 1 " " 9" " "	1.60	1 15	35	20	12	0.14	0.20	0 27
8	" 2 " " 6" " "	1.95	1 15	35	20	12	0.13	0.19	0.27
9	" 1 " " 6" " concrete	1.60	1 15	35	20	10	0.13	0.19	0 33
10	" 1 " " 9" " "	1.85	1 15		25	15		0.17	0 25
11	Sheet asphalt on 6" of concrete	3.00	2 00	15	8		0.44	0.69	
12	Granite on concrete	3.50	2 00	50	30	16	0 21	0.30	0 47
13	" " 6" of rubble	3.15	2 00	50	25	12	0 20	0 29	0.50
14	Cobble stone on 6" gravel	0 90	0 70		15	8		0.15	0 23
15	Macadam, granite top dressing.	1 35	0.75	10	6		0 23	0.35	..

904. Table 64, page 587, gives the estimated average cost of several kinds of pavements, computed upon a little different basis than the two preceding tables, by a man having wide experience in paving matters.†

"The data assumed in computing this table may be regarded as fair averages for pavements located in cities in the Mississippi Valley, on streets having a traffic of about 33 tons per day per foot of width. The tonnage assumed corresponds to that on a rather heavily traveled residence street, or a business street of medium travel, in cities of 100,000 to 200,000 population, and the result might be entirely different for a street having a larger or a smaller volume of travel. The interest in the table includes that on the cost of construction and on the annual expense for repairs, the latter being computed on the assumption that this expense is uniformly distributed over the last two thirds of the life of the pavement."

* D. W. Mead, in Jour. Assoc. Eng'g Societies, Vol. 11, p. 589.

† S. Whinery, in Trans. Assoc. Civil Eng'rs of Cornell University, 1900, p. 100.

TABLE 64.

ESTIMATED AVERAGE ANNUAL COST OF VARIOUS PAVEMENTS IN CITIES OF THE MISSISSIPPI VALLEY.

Ref. No.	Items of Expense.	Granite Block on Concrete.	Granite Block on Sand.	Sheet Asphalt.	Brick on Concrete.	Brick on Sand.	Cedar Block on Concrete.	Cedar Block on Sand.	Cobble Stone.	Macadam.
1	Cost of construction.......	$3.75	$3.20	$2.40	$2.15	$1.50	$1.80	$1.15	$1.00	$1.20
2	Annual cost of repairs......	.40	.60	.50	.45	.48	.36	.30	.48	1.00
3	Interest at 6 per cent......	4.66	3.06	2.31	1.66	.80	.69	.31	.54	.46
4	Total cost............	8.81	6.86	5.21	4.26	2.78	2.85	1.76	2.02	2.66
5	Value of old pavement.....	.76	.18	.72	.78	.14	.48	.12	.10	.10
6	Net total cost.........	8.05	6.68	4.46	3.48	2.64	2.07	1.64	1.92	2.56
7	Estimated life of pavement, years	20	15	15	12	8	6	4	8	5
8	Total cost per year....	$0.40	$0.44	$0.30	$0.29	$0.33	$0.34	$0.41	$0.24	$0.51
9	Net cost per year..........	0.25	0.24	0.19	0.18	0.16	0.12	0.15	0.13	0.29

The original table gives only the total average annual cost of the several pavements during their estimated life, i.e., the original table ends with the eighth line of Table 64; and the ninth line was computed as follows: The difference between the cost of construction and the value of the old pavements was divided by the number of years representing the estimated life of the pavement, and the quotient was subtracted from the total cost per year.

905. An examination of the three preceding tables shows that the life of the pavement, or the cost of perpetual maintenance, is the most important matter in comparing the relative economy of two or more pavements. The estimated relative degree in which the several pavements in Table 61 possess the desirable quality of low cost of maintenance is shown by the percentages in line 2 of that table.

906. Value of Ease of Traction. Under this may be included not only the power required to move loads but also the consequential damages to vehicles, since they both vary with the roughness of the pavement. From a study of the results in Table 9, page 31, the weights are assigned to this quality for the different kinds of pavements, as shown in Table 61.

907. Value of Foothold. From a study of § 887, the relative degree of slipperiness is stated in numbers and entered in Table 61. If the pavement is to be upon a steep grade, this quality may be a controlling factor.

908. Importance of Ease of Cleaning. The relative ease with which certain types of pavements may be swept, as determined by the cost of doing the work in New York city, is as follows: asphalt, 100; brick, 100; rectangular hard-wood blocks, 100; granite blocks, 150; Belgian blocks, 160; cobble stones, 400.* For sanitary reasons, New York city has spent a million dollars a year for the past few years in substituting sheet asphalt pavements for stone block in the congested tenement districts, chiefly on account of the greater ease with which the asphalt is kept clean.

The cost of sweeping ordinary stone block, round wood block, and brick with sand filler usually ranges between 40 and 48 cents per 1,000 square yards for each sweeping, and sheet asphalt from 30 to 38 cents, depending upon the thoroughness of doing the work, the frequency of sweepings, the kind of business in the property adjoining, and the amount of the traffic. The relative weight to be assigned to this item will vary with the frequency of cleaning.

The estimated weight to be assigned to the several pavements on account of their ease of cleaning is entered in Table 61, page 583.

909. Value for Other Qualities. From a consideration of the discussion in § 892–96, the percentages for the other qualities are inserted in Table 61.

910. Conclusion. The totals at the foot of Table 61, page 583, represent the summation of the individual decisions on the several qualities, and the larger the total the more desirable the pavement. The particular results in this example may not be applicable to any locality, and each person will have his own opinion as to the merits and defects of any particular pavement; but the method of analysis is applicable to any particular case, and will enable the engineer intelligently and unerringly to reach the

* Street Cleaning in New York City in 1895–97, p. 157—Supplement to Vol. II. of Municipal Affairs. New York, 1898.

final conclusion to which his opinion in detail leads. The above method has something of the mathematical form, but the fact should not be forgotten that it is based upon judgment and that therefore it can not be expected to give results of a high degree of accuracy.

In practice the application of this method is much less complicated than appears from the above example, for usually proximity of some natural pavement materials or freight rates on others, limits the choice to a comparatively few kinds of pavements. Further, the decision as to the kind of pavement to be laid is often influenced by the fancy or ability of those who pay for it. However, the engineer should employ a logical process in arriving at his own conclusions, and thus be in a position to give sound advice upon the economic principles involved.

CHAPTER XIX.

SIDEWALKS.

912. Sidewalk is the term ordinarily applied to the foot-way pavements usually placed on each side of the carriage-way pavements; and will be here employed to include also foot-way pavements in public parks and private grounds.

913. LOCATION. On business streets the sidewalk usually extends from the building line to the curb; but on residence streets the sidewalk is usually not so wide as the space from the property line to the curb, and hence there is a choice as to its location. The inner edge of the walk is usually placed about a foot from the property line or from the line marking the limit of steps, areaways, courtyards, etc., a grass plat intervening between the walk and the curb, but in a few cases the outer edge of the walk is placed next to the curb. The former position is more satisfactory than the latter, since pedestrians are further removed from the dust and dirt of the street, from the street sprinkler, and from horses tied at the curb, and are better protected from street traffic, which is an important matter in the case of children. Further, if the sidewalk is next to the curb, the trees either are further removed from the pavement and consequently do not give as good an appearance to the street and are likely to shut out light and air from the abutting houses, or are planted in notches or pockets left in the sidewalk, a method which reduces the available width of the walk and mars its symmetry. The only advantage claimed for the sidewalk next to the curb is that the yards are thereby virtually enlarged; but the grass plat is practically as valuable between the walk and the curb as between the walk and the property line. The sidewalk next to the curb appears to be the practice in Washington, D. C.

914. WIDTH. On residence streets in small cities, the walk is usually 4 to 6 feet wide; and on streets solidly built up with houses several stories high, the walk is 8 or 10 feet wide, unless the street is a thoroughfare or a promenade, in which case the width of the walk is greater. In Washington the walk on each side of the carriage-way pavement is about 15 per cent of the width of the narrower streets and about 10 per cent of the wide avenues; and in Chicago the sidewalk is roughly about 20 per cent of the width of the street, except for streets under 50 feet wide where it is about 15 per cent.

A number of the states provide by law for a sidewalk space on either side of the road, "where possible," equal in width to one tenth of the right of way, and make it a misdemeanor to ride or drive horses upon this space. Many, perhaps most, of the rural roads of Europe have a well-paved sidewalk on one side and rows of trees upon both sides; but in this country there are almost no artificial foot-paths upon the side of rural roads.

915. TRANSVERSE SLOPE. The surface of sidewalks should slope from the property toward the curb, to shed rain water toward the gutter. This transverse slope varies from 1 inch in 3 feet to 1 inch in 5 feet, the former for the rougher walks, as brick, and the latter for the smoother ones, as asphalt and cement.

If the walk is on the side of a street, it should have a uniform slope toward the center of the street; but if it is in a park, the surface should have sufficient crown to shed the water to the sides and to keep the surface free from standing water. This crown should be no more than is required to drain the surface, since an excess causes traffic to keep in the center of the walk. The crown in any particular case will depend upon the material employed for the surface and will be discussed in subsequent sections.

The lower edge of a sidewalk should be sufficiently above the surface of the adjoining ground to give perfect drainage to the surface. In public parks and private grounds the surface of the walk should be 2 or 3 inches above the general level of the ground, in order that the walk may not become a drainage channel.

916. GRADE. The longitudinal slope of the sidewalk must conform, at least approximately, to the grade of the street; and ordinarily if vehicles can use the carriage-way pavement, pedes-

trians can use the sidewalk, unless it is proportionally considerably smoother than the carriage-way pavement, in which case the sidewalk may be built in sections having flatter grades with one or more steps between the sections.

In considering whether or not to cut down a hill or to fill up a hollow to decrease the rise and fall (§ 66) of the sidewalk, it is well to remember that, measured by the energy expended by a pedestrian, a rise of 1 foot is equivalent to a horizontal distance of about 18 feet (see foot-note on page 58).

917. Sidewalk across Private Driveway. Very often the driveway from the street across the sidewalk to gates or into buildings is constructed with an offset of from 2 to 6 inches where the walk meets the driveway, as shown in Fig. 146. This depres-

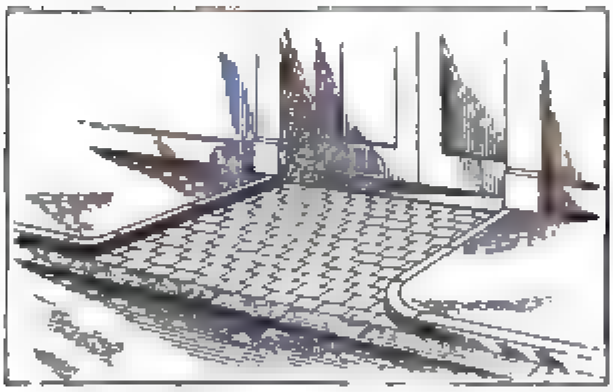

FIG. 146.—DEPRESSED DRIVEWAY ACROSS WALK.

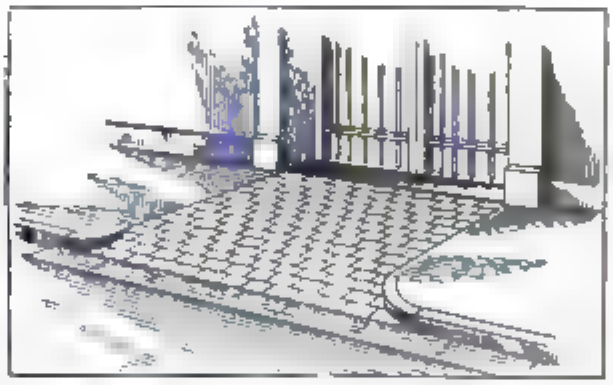

FIG. 147.—PROPER DRIVEWAY ACROSS WALK.

sion is often unseen by a pedestrian until he steps into it with a a sudden jolt. The depression detracts from the symmetrical appearance of the walk, and is an entirely needless source of danger. Fig. 147 shows a much better and also a cheaper arrangement. When it is necessary to provide for surface drainage from the private property, the driveway may be paved with an almost imperceptible depression in the center which will conduct the water into the gutter.

918. MATERIAL. Sidewalks are constructed of asphalt, brick, hydraulic cement concrete, cinders, gravel, macadam, plank, stone slabs, and tar concrete. The method of construction for each of these materials will be considered separately in the above (alphabetical) order.

919. ASPHALT WALKS. Asphalt is used for sidewalks both in the form of a monolithic sheet and in blocks or tiles, in much

the same way as for carriage-way pavements, except that the foundation need not be so strong nor the wearing coat so thick.

920. Sheet Asphalt. The material for the wearing coat of artificial sheet asphalt foot-way pavements may be mixed softer than for carriage-way pavements, as the former are not required to bear the heavy loads of the latter. The softer the mixture the greater its life, since the greater the amount of oil the longer the time before the pavement will be rendered brittle by the effect of volatilization and oxidation. Asphalt is unsuitable for unfrequented walks, since cracks due to expansion and contraction are not re-cemented by the pressure of traffic (§ 654). Monolithic asphalt foot-way pavements are not common in this country, the only city in which they are used to any considerable extent being Washington, D. C., where the material removed from old asphalt carriage-way pavements in making repairs and in re-surfacing is used for foot-ways. Such pavements with a 3-inch hydraulic-cement concrete base and a 1-inch wearing coat usually cost, exclusive of grading, from 90 cents to $1.00 per square yard.

Sheet asphalt foot-way pavements are used to a considerable extent in European cities, particularly in Paris. They are made of asphalt mastic or, in French, *asphalte coulé*, which consists of an asphaltic limestone to which has been added some asphalt, usually that from Trinidad. The material is heated and carried to the walk in buckets, and being of a consistency to flow slowly is poured out upon the foundation and spread to the desired thickness, usually about ⅝ of an inch, and smoothed with wooden floats. Some coarse sand is usually rubbed into the surface to keep it from being slippery. When cool the pavement is ready for use.

921. Asphalt Tiles. Asphalt sidewalk-paving tiles are made 2½ inches thick having a top surface 8 inches square or a hexagon of the same area. For a description of the composition of the blocks and of the method of making them, see Art. 4, Chapter XIII, page 447. The blocks, or tiles as they are commonly called, are laid substantially as described for asphalt block carriage-way pavements—see § 682–91.

922. BRICK SIDEWALKS. Brick sidewalks are very common, and when properly constructed are cheap, durable, and reasonably satisfactory. Commonly they consist of ordinary hard-burned

building brick laid flatwise upon a porous bed of sand or cinders, although occasionally in heavily traveled business districts the bricks are set on edge and the joints are filled with cement mortar.

923. Foundation. If the soil is a very retentive clay, or if the foundation is not well drained, the foundation should be excavated to a depth of 10 inches; but if the soil is an ordinary loam, a depth of 8 inches is sufficient. All loose or spongy material should be removed; and the subgrade should be formed parallel to the surface of the finished walk.

Upon the subgrade should be spread a layer of clean coarse sand or fine gravel or cinders, to furnish a firm unyielding support for the bricks. If laid upon a foundation that became plastic when wet, the bricks would work down into the foundation and the mud would work up between the bricks, thus making the walk temporarily muddy and permanently rough. Whatever the material employed for the foundation, it should be thoroughly consolidated by tamping or rolling; and if cinders are used, particular care should be given to the tamping, so that the larger clinkers shall be broken up and the finer particles be worked in around the coarser pieces. A thorough flooding is beneficial in consolidating cinders, as the water aids in working the fine material into the interstices between the larger pieces. If flooded and well tamped, cinders will consolidate to about three fourths of their thickness when loose. Cinders containing fine ashes are undesirable for sidewalk foundations, since it is difficult to consolidate them, and since the ashes are likely to be washed to the bottom by rains and thereby to cause the surface of the sidewalk to settle. Cinders made by steam plants, sometimes called steam ashes, are better for this purpose than are household ashes, since the fires in the former are hotter and fuse most of the ashes into cinders, leaving little or no fine material. Steam cinders that have been drenched with water as soon as drawn from the furnace, usually called black cinders, are better than those that have been allowed to burn in the pile, since they contain fewer fine ashes. Wood ashes are very objectionable, since they contain a great deal of fine material, and since a considerable part is soluble and will wash entirely away thus allowing the surface to settle.

Upon the foundation of gravel or cinders should be placed a

layer of sand 1½ or 2 inches deep to serve as a cushion upon which to lay the bricks (see § 761).

924. The Bricks. The bricks should be hard-burned and have plane parallel surfaces and sharp right-angled edges. They should give a clear ringing sound when two are struck together, and when broken should show a compact uniform structure free from air bubbles and cracks. They need not be burned as hard as is required for carriage-way pavements (§ 723); but they should be equally as carefully selected to secure a uniform quality and thereby insure uniform wear. Most sidewalks are made of hard-burned ordinary building bricks; but sometimes they are con-

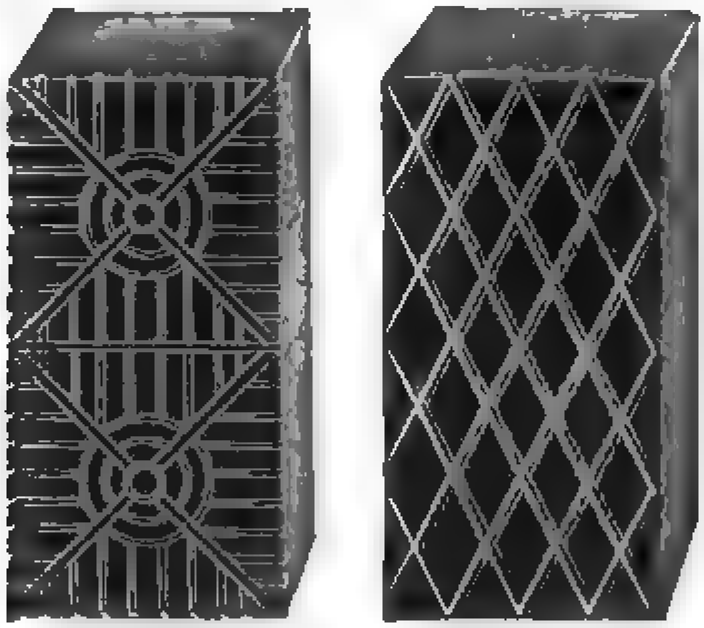

FIG. 148.—CORRUGATED SIDEWALK BRICK.

structed of re-pressed bricks, which give closer joints and more uniform surface. Thin joints are desirable, since they decrease the tendency for weeds and grass to grow in them. Sometimes sidewalk bricks are made with a corrugated top surface, of which Fig. 148, shows two forms; but the corrugations are of no advantage, and it is hard to clean the snow out of them. Occasionally salt-glazed brick (§ 734) are used in sidewalks; but this is undesirable, since the glazing makes the bricks slippery and also makes it more difficult to detect soft bricks.

925. Direction of Rows. There is considerable difference in practice as to the position of the bricks with reference to the side of the walk. The arrangement shown in Fig. 149, page 596, is apparently the most common, and may be called the longitudinal herring-bone. The arrangement in Fig. 150, page 596, is superior

to that in Fig. 149, since there are usually no bricks in the triangular corners near the edge of the walk, and weeds and grass grow in them, thus giving the walk an untidy appearance. Some manu-

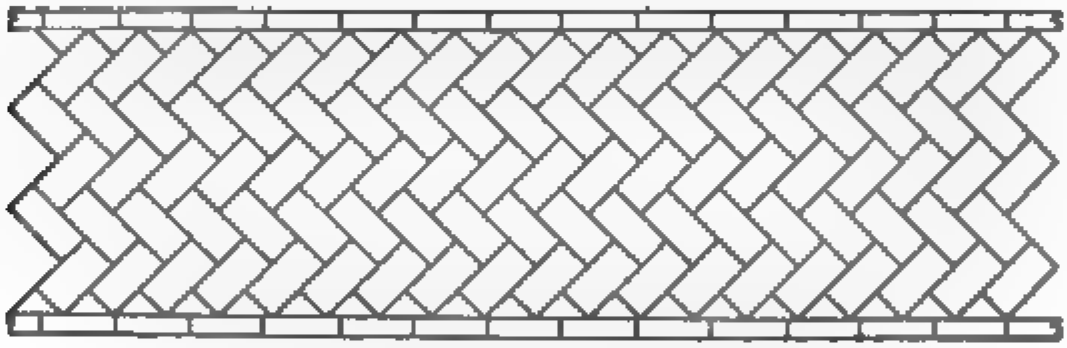

FIG. 149.—LONGITUDINAL HERRING-BONE BRICK SIDEWALK.

facturers make triangular pieces with which to fill these corners, but such an arrangement will cost more than that shown in Fig.

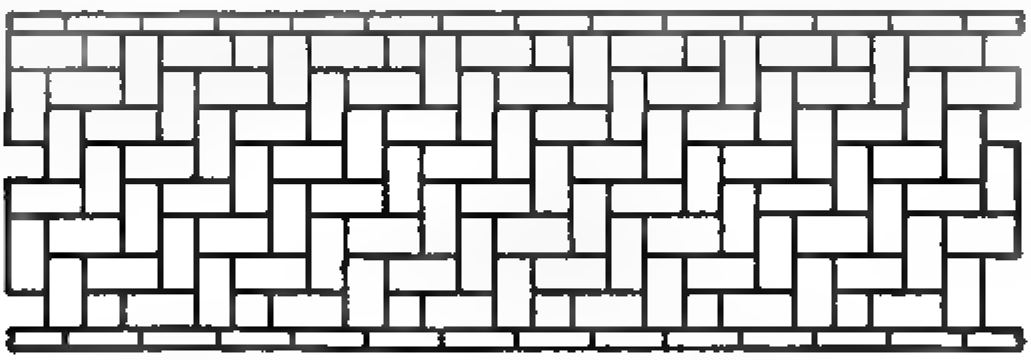

FIG. 150.—DIAGONAL HERRING-BONE BRICK SIDEWALK.

150. Fig. 150 is easier to lay than Fig. 149, since it is less difficult to maintain the direction of the courses. Possibly there is slightly

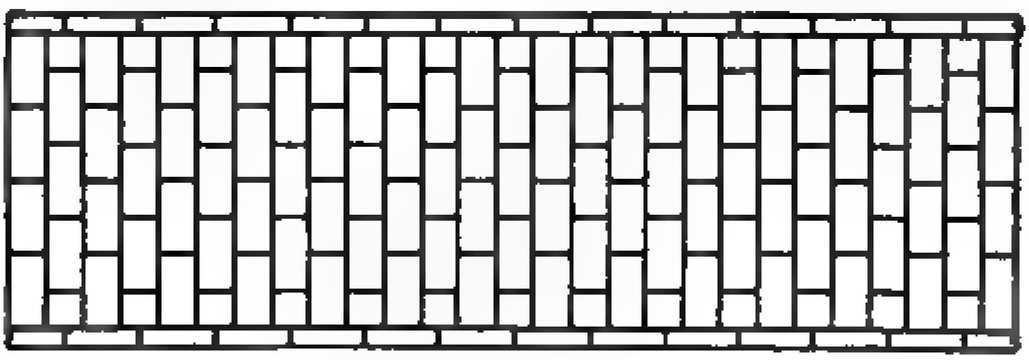

FIG. 151.—SQUARE-COURSE BRICK SIDEWALK.

less danger of stubbing one's toe on a walk laid as in Fig. 149 than on one laid as in Fig. 150. Fig. 151 and 152 show two other arrangements of the bricks; but neither of these is as good as either

Fig. 149 or Fig. 150, on account of the continuous joints making the displacement of the bricks more likely when wheelbarrows, baggage trucks, or other wheeled vehicles are run over the walk. A pleasing variety is sometimes obtained by introducing different colored bricks, as for example dark-colored and buff bricks.

The side of the walk is usually protected by setting a row of

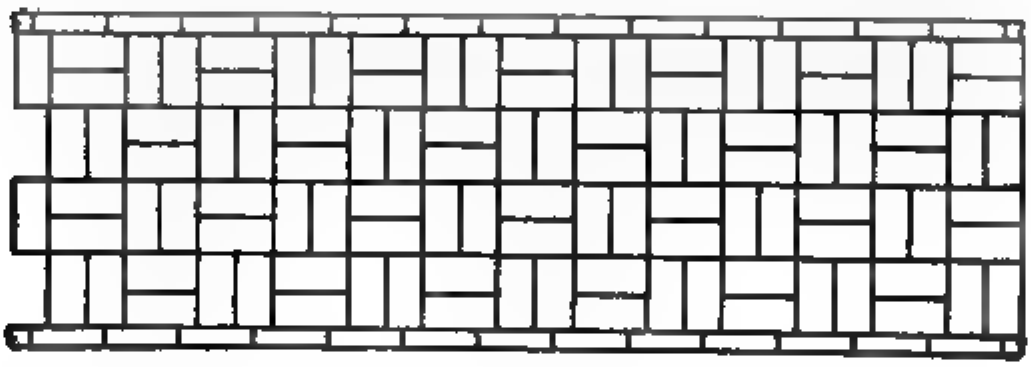

FIG. 152.—BLOCK-IN-COURSE BRICK SIDEWALK.

bricks on edge, as shown in Fig. 149–52. Sometimes the bricks are set on end to form a curb, and some manufacturers make a brick block or tile 8 × 8 × 2 inches to be used as curbs for sidewalks.

926. Laying the Bricks. On each side of the gravel or cinder foundation should be placed a line of scantlings approximately 2 × 4 inches, whose top edges should accurately conform to the top of the curbs of the finished walk. Between the scantlings is then placed a 2-inch layer of fine clean dry sand upon which to bed the brick. This sand should be spread fairly uniformly with shovels, and then its top surface should be made smooth and uniform and exactly parallel to the surface of the finished walk, by drawing over it a template whose ends run on the scantlings. For several precautions applicable in this work, see § 763 and the first and last paragraph of § 764.

After the sand bed has been properly prepared, the bricks are to be laid by men standing upon the brick already in position without disturbing the sand cushion. Care should be taken to preserve the direction of the courses and also to secure joints of uniform width, so that there may be neither a needlessly wide joint in closing nor any cutting of the brick. The bricks should be laid with as close joints as possible, for appearance and to prevent as far as possible grass and weeds from growing in the joints.

The surface of the walk should be carefully and thoroughly rammed to settle all the bricks firmly and uniformly into the sand cushion. The ramming may be done with either of the rammers shown in Fig. 138 and Fig. 141, page 527 and 543, respectively. The rammer should be used upon a hard wood plank 2 inches thick, 1 foot wide, and 6 or 8 feet long. Any unevenness of the surface after the walk has been rammed should be corrected by taking up and re-laying the defective area. After the walk has been rammed, the joints are filled with fine dry sand, and a layer about $\frac{1}{4}$-inch thick is left upon the surface to be further worked into the joints by traffic.

927. If the earth comes directly against the edge or curb of the sidewalk, it will stick to the bricks when wet, and in drying will contract and pull the bricks away from each other. The cracks thus formed will fill with dirt, and the process will be repeated the next dry spell, and thus the joints will be gradually widened. This action is entirely prevented by placing 3 or 4 inches of sand between the bricks and the earth.

Some cities use a concrete curb at the edge of the brick walk. This curb is sometimes 2×8 inches, and sometimes 6×6 inches. The cost of a concrete curb is hardly justifiable, since the chief advantage of it is obtained by the use of sand as described in the preceding paragraph.

If the center of the walk is above the surrounding surface and particularly if it is on an embankment, there should be considerable earth against the sides of the walk to prevent the expansion of water freezing in the joints from crowding the curbs out and increasing the width of the joints.

928. Transverse Slope. A brick sidewalk should be laid with a slope toward the street of $\frac{3}{8}$ or $\frac{1}{2}$ an inch to the foot, to secure surface drainage. Not infrequently brick sidewalks bounded by grass plats on both sides are laid with the two sides on the same level, and the center is raised an inch or more. This practice is undesirable, since the gutter formed at each side of the walk becomes a channel to carry the water longitudinally along the walk, whereas the water should be permitted to flow across the walk into the street gutter. Occasionally the crown is made so great as to confine the travel to the center.

929. Brick Crossings on Unpaved Street. These are usually laid substantially as a two-course brick pavement. The subgrade is excavated to a depth of 14 to 16 inches, according to the character of the soil and the volume of the traffic, below the top of the finished crossing. The foundation should be excavated, say, 6 inches wider on each side than it is proposed to lay the bricks, in order that there may be a shoulder or footing to support the outer brick; and the edges of the foundation should have a crown of, say, 6 inches, most of which should be at the edge so that the finished crossing may have a slope at the sides that will be easy for vehicle wheels to mount. After the soil has been tamped to consolidate it and to reveal any soft place, a layer of gravel or cinders 6 to 8 inches thick is then laid and tamped. Upon this foundation is placed a layer of hard-burned building bricks laid flatwise. The joints of the lower course of bricks is swept full of fine sand, and a cushion coat of 2 inches of sand is left upon the brick. The top surface of the sand cushion should be brought parallel to the finished surface of the proposed crossing, by the use of a lute or hand scraper. The sand cushion is then covered with very hard-burned building brick or with rejected paving bricks or blocks, set on edge and properly breaking joints. These bricks are then thoroughly rammed, and the joints are swept full of fine sand.

930. Crossings on Brick Pavement. On unpaved streets crossings are laid to keep pedestrians out of the mud, and on rough stone-block pavements crossings are constructed to provide a smooth surface which is more pleasant to walk upon and also more easily cleaned than the carriage-way pavement; but on streets paved with a smooth hard surface which is easily cleaned, as brick, special foot-way crossings are not necessary, except to aid pedestrians in crossing the water in the gutters. To confine the water in the gutter, it is customary to raise the pavement in the line of the crossing so that the surface is level, or nearly so, from the crown of the carriage-way pavement to the curb, leaving a channel next to the curb which is either left open or bridged with a cast-iron plate. Fig. 153, page 600, shows the details of an elevated brick crossing. Notice that Fig. 153 has a limestone curb and a brick gutter. Fig. 154 and 155, page 600, show the gutter at the end of an elevated brick crossing when a concrete curb and gutter is employed. The

chief difference between Fig. 154 and 155 is in the form of the false curb or head stone on the side of the gutter toward the center of the street. The difference in the merits of the two methods is mainly in the cost, Fig. 154 usually being slightly the cheaper.

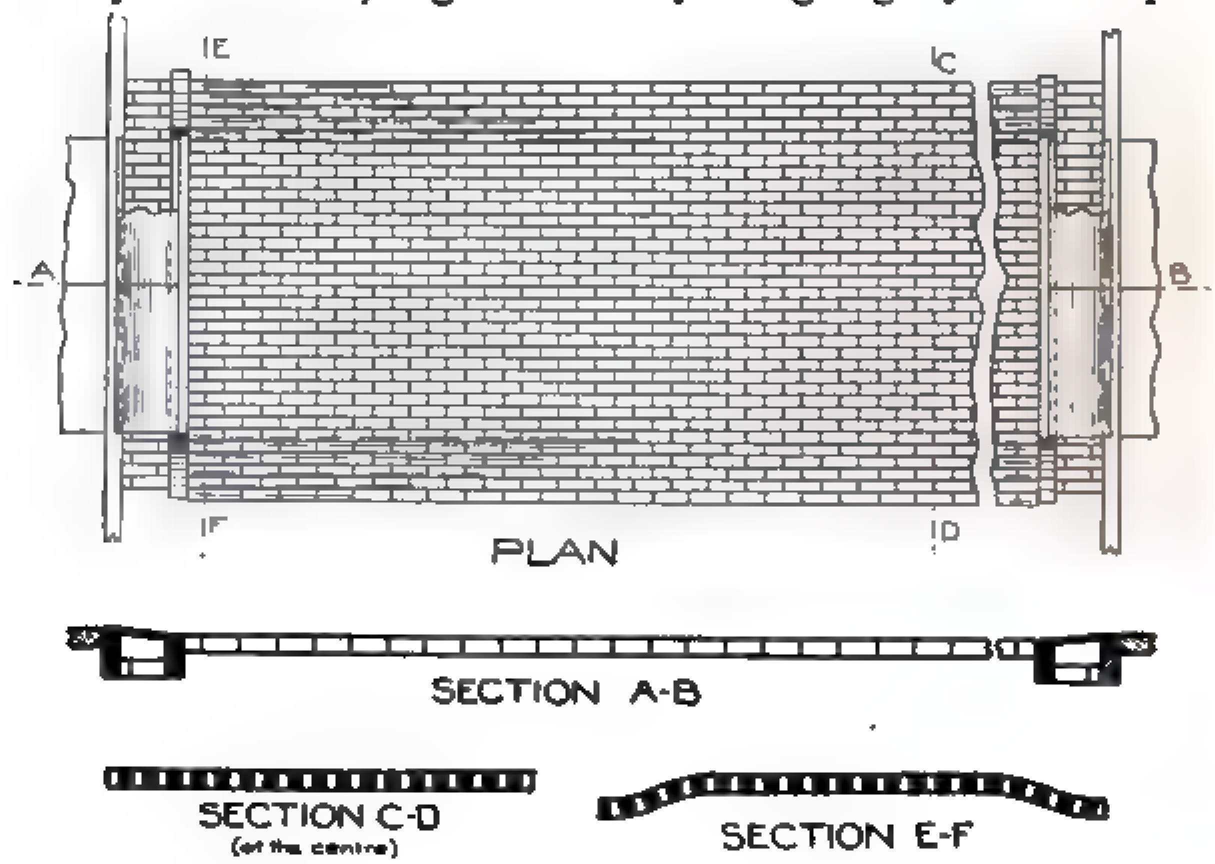

FIG. 153.—ELEVATED BRICK CROSSING.

In both cases there is a drop of 1 inch in the width of the cast-iron bridge plate. Of course, the crossing could be carried level from gutter to gutter, or more drop could be put into the gutter plate.

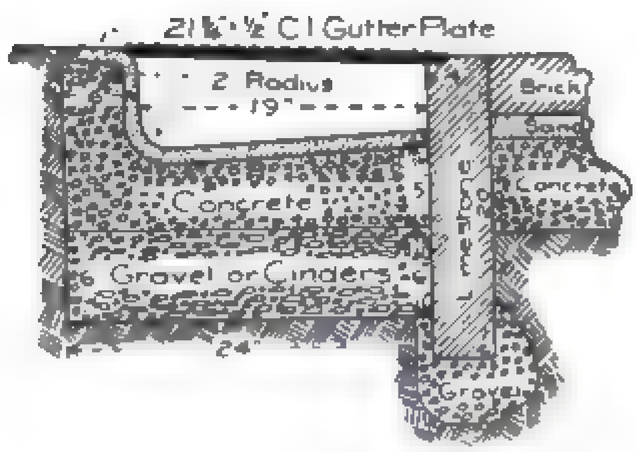

FIG. 154.—GUTTER FOR ELEVATED BRICK CROSSING WITH LIMESTONE FALSE CURB.

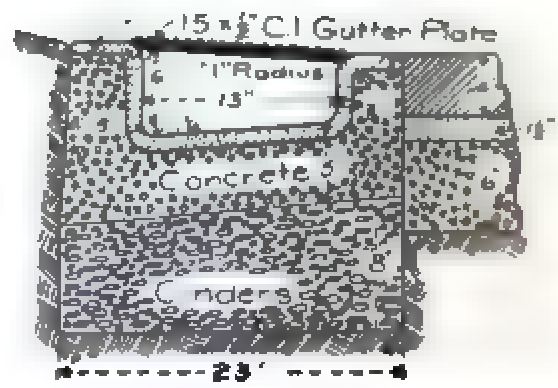

FIG. 155.—GUTTER FOR ELEVATED BRICK CROSSING WITH CONCRETE FALSE CURB.

As far as the use of the carriage-way pavement is concerned, an elevated crossing is undesirable, particularly where the pavement is used by a large number of vehicles or where there is con-

siderable rapid traffic; but elevated crossings are a necessity where a considerable volume of water is brought to a corner catch-basin or where the street is nearly level longitudinally. Some of the disadvantages of an elevated crossing are eliminated by placing a catch-basin at each side of the corner instead of one at the corner —see § 507.

It has been proposed to cast the street names on the bridge plates used at elevated crossings. This can be done at a comparatively small cost, and would put the street name in a convenient place for pedestrians; but unfortunately these plates frequently get broken, and further the name on the crossing plate would not be visible from vehicles and street cars.

931. Cost. The price of bricks suitable for sidewalks is usually from $7.00 to $9.00 per thousand. Table 51, page 518, shows the number of bricks required to lay a square yard. The cost of the earthwork will vary with the character of the soil and the depth of the excavation. The cost of labor in placing the sand cushion and laying the brick, varies from 4 to 4½ cents per square yard.

The following is the actual cost of half a mile of 6-foot brick walk laid by contract in a city in Central Illinois:

Items.	Cost per Sq. Yd.
Excavation at 15 cents per cubic yard	$0.063
Sand and gravel 12 inches thick at $1.00 per cubic yard	.333
Brick at $7.00 per thousand, delivered	.259
Labor at $1.50 for 10 hours	.043
Total cost to contractor	$0.698

The following is the cost of constructing a brick pavement 859 feet long and 6 feet 2 inches wide by the city's force in a city in Central Illinois:

Items.				Cost per Sq. Yd.
Brick at $8.00 per thousand, delivered				$0.352
Cinders at 25 cents per cubic yard, at furnace				.042
hauling same, 1 day at $3.00				.005
Sand at 80 cents per cubic yard, delivered				.041
Labor: excavating—men,	10	days at	$1.50	.033
team,	1½	" "	3.00	
preparing subgrade,	8	" "	1.50	.020
grading cinders,	6	" "	1.50	.015
setting forms,	2	" "	1.50	.005
laying brick,	16	" "	1.50	.041
setting curbs,	6	" "	1.50	.010
filling joints, etc.,	6½	" "	1.50	.017
Total cost				$0.581

932. Merits and Defects. Brick sidewalks are cheap, fairly smooth, and not slippery; and if made of hard brick are dry in damp weather and durable under very heavy travel. Their defects are: (1) they are rough in comparison with asphalt, cement, and the best stone slabs; (2) they are untidy, since grass and weeds are likely to grow in the joints.

933. CEMENT SIDEWALKS. This is the term usually applied to an artificial-stone walk composed of a hydraulic-cement concrete base and a cement-mortar top. Such a construction is sometimes called a concrete walk, and sometimes a granolithic walk. Numerous patents have from time to time been issued for various details of cement walk construction, but the essential features are not covered by patents. Within the past few years cement walks have become very common, not only in the cities of the Mississippi Valley, where natural stone suitable for walks is quite expensive, but also in the eastern cities, where suitable natural stone is plenty and cheap. Cement walks are smooth, pleasing in appearance, reasonably cheap, and when well constructed are very durable.

934. Foundation. The foundation for a cement walk should be practically the same as that for a brick walk (see § 922). Since the cement walk is composed of large rigid blocks, it apparently does not require so heavy a foundation as a brick walk; but, on the other hand, a slight settlement of the foundation is more serious with a cement walk than with a brick one, which fact seems to show that the cement walk should have a heavier foundation than a brick one. Water freezing under a cement walk is liable to crack and displace the blocks; and therefore if the soil is retentive or is not already artificially underdrained, it is wise to lay a line of tile longitudinally under the proposed walk, which shall have a sufficient outlet to carry the subsurface water entirely away. It is not uncommon to excavate the foundation 1½ or 2 feet below the surface of the proposed walk, apparently that the porous foundation may act as a drain or a reservoir to prevent water from standing against the lower side of the concrete and perhaps freezing and lifting the walk; but a tile subdrain is cheaper and more effective than a deep but undrained foundation. If the underdrainage is even fairly good, a depth of 6 inches of cinders or clean gravel will make a satisfactory foundation, provided it is firmly and uniformly

tamped; and with poor drainage the thickness need not be more than 8 inches. On residence streets in small cities, 4 inches of cinders or gravel with fair drainage would doubtless be sufficient, although the foundations are usually made much thicker.

The finished surface of the subgrade should be made exactly parallel to the top of the proposed walk. To secure this condition, some engineers specify that the depth of the subgrade is to be gaged by a template run on the top of the forms after they have been placed.

935. The Forms. The edge of the walk is marked by a 2-inch by 4-inch scantling securely staked in position with its top face in the plane of the top of the finished walk. These scantlings should be blocked up so as accurately to maintain the longitudinal grade of the walk, and should also be so securely staked that they will not be crowded out by the tamping of the concrete.

The forms for short curves should be made by sawing the proper curve out of an inch plank, and then nailing enough of them together to give the proper thickness. Care should be taken in joining the straight form to these curves, to prevent an unsightly change of direction. Large curves can be made by using a ½-inch by 4-inch plank on edge for the side, and springing it into the proper curve and staking it fast; but care must be taken with the ends of adjacent pieces to secure a uniform curve.

936. Concrete Base. In residence districts of small cities, the base is usually 3 inches thick; but on residence streets of large cities it is often 4 inches, and on business streets it is sometimes 5 inches. The base consists either of a rich natural-cement concrete or of a rather lean Portland-cement concrete. The latter is the more common, and the relative merits of the two classes of cements for this purpose will be considered presently (see § 945). For a discussion of the theory of proportioning the concrete, see § 549; and for the method of mixing, see § 557.

Any moderately hard stone is suitable for making the concrete base; and the stone is usually crushed to pass a 1-inch ring. For a discussion of the relative merits of gravel and broken stone for use in concrete, see § 553. It is important that the sand or gravel used in the concrete base be clean, so that in tamping a film of clay may not work to the top and make a surface of separation between

the concrete base and the mortar top. The following proportions are common: 1 part Portland cement, 3 parts sand, and 6 parts of unscreened broken stone (see § 555).

The concrete should be mixed rather dry in order that there may not be a film of water on the top of the concrete base which will prevent a firm union between the top and the base. If the concrete is too moist, the mass will shake like wet clay; if it be too dry, it will rise up around the rammer like sand. In either case, the mass can not be suitably compacted by ramming, and will therefore be comparatively weak and porous after setting. The concrete should be thoroughly and uniformly tamped until moisture flushes to the surface. Particular care should be taken that the concrete base is well consolidated along the outer edges, so that frost will not break them up. This point is often neglected, because tamping the edges is likely to crowd the forms out of place.

It is important that the upper surface of the concrete base should be exactly parallel to the top of the finished walk. To determine whether this condition is fulfilled draw a properly-made template over the tops of the side forms.

937. The concrete is cut into blocks by laying a straight edge on the marks previously made on the side forms (§ 942), and resting a short but broad blade, see Fig. 156, against the straight edge and driving it downward by striking it with an iron concrete-tamper. After the blade has been driven to the bottom of the concrete, it is drawn out and moved along, and the process is repeated until the concrete is cut through across the entire width. Some engineers specify that the space made by the cutting tool shall be immediately filled with fine sand; but it is better to leave it entirely open (see § 942).

938. Wearing Coat. This must be made of Portland cement, since natural cement is not sufficiently strong to resist the abrasion of traffic and the effect of freezing and thawing. The wearing coat is usually composed of one part of Portland cement and one or two parts of clean, sharp, coarse sand or the same amount of granite or quartz screenings that will pass a sieve having $\frac{1}{4}$-inch meshes. The proper proportion of sand to cement depends upon the voids in the sand. There should be enough, and only enough, cement to fill the voids. If there is not enough cement to fill the voids,

the sand will not be held with the maximum strength; and if there is an excess of cement, the walk is liable to crumble under travel, since neat cement will not resist abrasion as well as sand and cement. Sand is not as good as screenings, but is cheaper and is much more commonly employed.

Sand frequently contains a considerable proportion of soft and easily decomposed constituents which renders it unfit for use in the

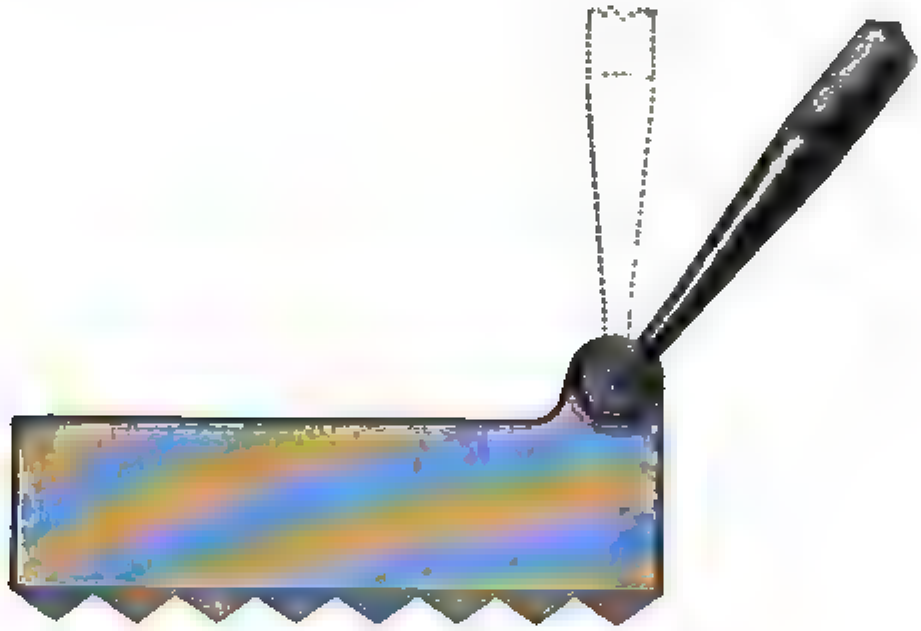

FIG. 156 —BLADE FOR CUTTING THE CONCRETE BASE.

wearing coat of cement sidewalks, since the friable grains soon pulverize and blow away, leaving a hole or pit in the surface, which not only looks badly but also tends to hasten the destruction of the walk. Granite screenings are frequently used instead of natural sand, but some granites contain mica, hornblende, and feldspar which render them undesirable for use in cement walks. Crushed quartz is best for this purpose, but is expensive on account of the difficulty of crushing it. Pure silica sand is entirely satisfactory. Screenings are considerably more expensive than sand (see § 955), and if used, should be perfectly free from fine dust.

The thickness of the wearing coat depends upon the amount of traffic, a thickness of ½ an inch being employed where the traffic is light, and 1 inch where it is heavy. The mortar for the wearing coat should be mixed rather dry, and should be applied before the cement in the concrete base has begun to set, in order that the two layers may firmly unite. The mortar is to be brought to a uniform thickness by laying a straight edge on the side forms and drawing

it longitudinally along the walk. The mortar should then be rubbed and compressed with a float (a plasterer's wooden spreading trowel) to expel the air bubbles and the surplus water. Just as the cement in the top coat begins to set, it is to be rubbed smooth and hard with a plastering trowel, sufficient pressure being employed to force the top and bottom layers into close contact so that they may firmly adhere.

Sometimes the mortar is inadvertently made too wet, and an excessive amount of water appears in floating and troweling, particularly on a cool damp day. To take up this water, dry cement is sometimes sprinkled over the surface; but this practice is very undesirable, since it leaves the surface too rich in cement and likely to be spotted in color. A surplus of cement makes the surface of the walk more friable than though the proper proportion of sand had been used. The best method of removing this excess of water is to absorb it with a dry mixture of cement and sand of the proportions used for the top coat, and then there will be no excess of cement and no spottedness.

In troweling, particular care must be taken to consolidate the edges of the blocks; and the general tendency to trowel the blocks low in the center must be carefully guarded against, as these depressions retain water after a rain and keep the walk needlessly wet. The troweling should be done so that when a 4-foot straight edge is laid in any direction upon the walk a space greater than $\frac{1}{8}$ of an inch will never be found under it, and seldom a space greater than $\frac{1}{16}$ of an inch will be found.

Troweling for an excessively long time is very objectionable, since it is liable to work an excess of cement to the surface, a result which makes the walk more slippery and less durable.

939. While completing the troweling, the wearing coat is to be separated into blocks by laying a straight edge to the marks previously made upon the side forms, and with the point of the trowel cutting through the wearing coat exactly over the cut previously made in the concrete base. The joint is then finished by rubbing it with a tool similar to that shown in Fig. 157. The edge of the walk also is finished by running over it a tool similar to that shown in Fig. 158, the front face of the tool as shown being placed next to the wood frame.

940. Some engineers specify that after the troweling has been finished and the joints and edges have been rubbed down, the entire surface shall be brushed with a damp bristle-brush, to remove the trowel marks. The brush-finish gives a uniform dull surface that appears better than the surface left by the trowel. See § 527.

Other engineers require that the surface shall be marked with a

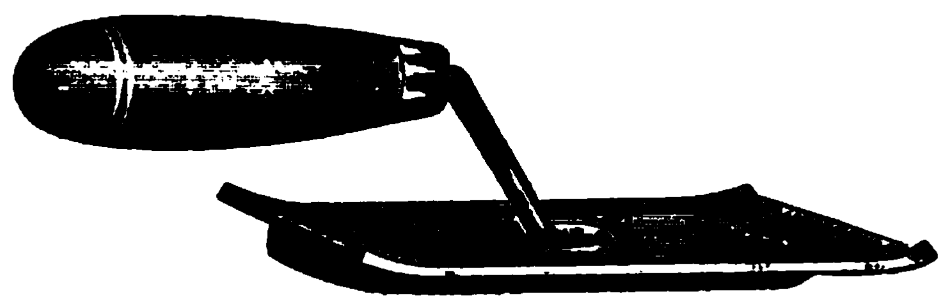

FIG. 157.—CEMENT-WALK JOINTER.

toothed roller somewhat like that shown in Fig. 159, page 608, the object being to render the walk less slippery (see § 952).

941. After the wearing surface is finished, the walk must be protected from the weather and other injury until it has thoroughly set. It is well to shield the walk from the direct rays of the sun and

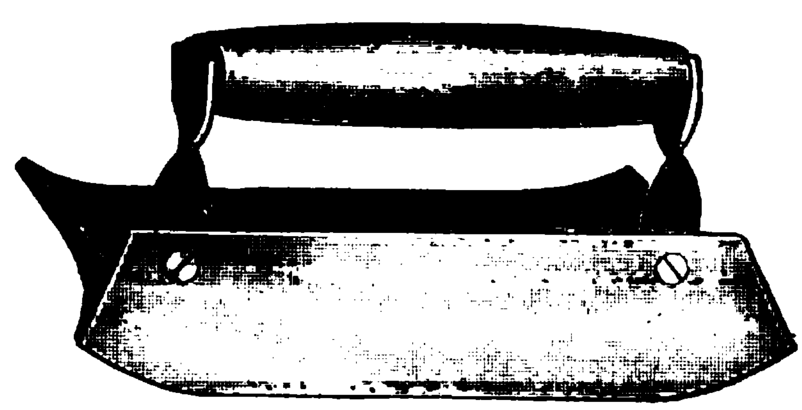

FIG. 158.—CEMENT-WALK EDGE-FORMER.

from strong winds for at least one day, in order that the water required for the setting of the cement may not be lost by evaporization. If the weather is dry, it is well to keep the walk moist by sprinkling it frequently; but it should not be sprinkled until the surface has hardened, lest it be pitted by the drops of water. In a very dry time, the necessity for frequently sprinkling the surface may be obviated by covering the walk with sand, straw, etc.

The forms should not be removed until the cement has set so hard that there is no danger of injuring the edge of the walk in removing them.

942. Joints. The walks should be formed in blocks from 3 to 8 feet square, to prevent settlement of the foundation or contraction by cold from making unsightly irregular cracks. If the walk is 5

inches thick, the blocks may safely be 5 or 6 feet square; and if the thickness is 6 inches, the blocks may be 7 or 8 feet square. The concrete base is usually laid in a continuous mass, and then cut into blocks, in which case the position of the joints should be determined and be marked upon the forms before the concrete is laid. The joints should be continuous across the entire width of the

FIG. 159.—CEMENT-WALK IMPRINT ROLLER.

walk, i. e., a joint should not come opposite the middle of a block, since settlement or contraction cracks are likely to start from the end of the joint across the middle of the adjacent block.

Some constructors to secure a more complete separation of the blocks, divide the area to be occupied by the walk into compartments by inserting transverse partitions between the side forms, and then construct the walk in alternate blocks. The only advantage of this construction is that it insures a complete separation between adjoining blocks; but the method described above has given no trouble in practice. A few constructors not only build the walk in alternate sections, but leave a steel partition about $\frac{3}{16}$

of an inch thick between adjacent blocks until the concrete has partially set. The object of the partition is to leave an open joint to give room for the expansion of the walk; but the joint is likely to get filled with dirt and sand, which will largely, if not wholly, neutralize the supposed advantage of the open joint.

943. In closing work at night, the concrete should be finished at a joint with a square straight end. If the concrete is finished with a ragged oblique edge, it is impossible to get a good union between the two days' work and expansion by heat is liable to cause one piece to slide upon the other and break the wearing course. The wearing coat also should be finished up to a joint. Sometimes an attempt is made to weld new mortar to that already set, but alternate freezing and thawing is likely to open a crack at the weld; and hence welding should never be permitted. The work may be stopped at night most conveniently by inserting a board between the side forms, and finishing the walk against it. No patching of a defective block after the cement has begun to set should be allowed.

944. Expansion. There is occasionally a little trouble from the expansion by heat of long stretches of cement walk constructed without open or expansion joints. The coefficient of expansion of concrete is about 0.000,005,5 per degree Fahrenheit.* The expansion of different walks differs according to the length of the walk, the exposure to the sunshine, the openness of the joints when first constructed, the anchorage at the ends of the walk, the circulation of air under the walk, the depth of the walk in the ground, etc. Damage by expansion seems not always to occur in the hottest weather, but no satisfactory reason is known for this anomaly.

The expansion of the walk sometimes causes two adjacent blocks to buckle up, producing more or less crushing and spalling of the edges. This occurs most frequently in the dip between two ascending grades, since the blocks in expanding move in the direction of the least resistance, and consequently gradually work down hill. The buckling of the walk may be prevented by inserting an occasional tar joint, say, ½ an inch thick. If a tar expansion-joint is used, the upper half inch of the joint should be filled

* Jour. West. Soc. of Eng'rs, Vol. 6, p. 559.

with sand to prevent the tar from being tracked over the surface of the walk. Damage by expansion is more common after the walk is two or three years old than before, owing to the fact that when first made there is more or less empty space in the joint which takes up the expansion; but this space gradually becomes filled with dirt, and no longer absorbs the expansion. The damage from expansion is not very serious. For example, a contractor who has laid 250,000 square feet of cement walk in the past ten years has been called upon to repair only five breaks due to expansion.

945. Natural vs. Portland Cement. Portland cement must be used for the top coat of walks, since natural cement is not strong enough to endure the abrasion of traffic and the effect of freezing and thawing; but as far as strength is concerned, the base could be made of either natural or Portland cement. Many skillful contractors claim that it is impossible certainly to make a Portland-cement top adhere firmly to a natural-cement base, and claim further that the same kind of Portland cement should be used in both the base and top so that a difference in the rate of set may not make a surface of separation between the top and base; while on the other hand, other contractors seem to have no trouble in using a natural cement in the base and a Portland in the wearing coat. Doubtless the latter succeed only by unusual care; and therefore it is safer to use Portland in the base, particularly as the failure of the wearing coat to adhere firmly to the base is the most common defect of cement walks, whether the base is made of natural or of Portland cement. Owing to the recent marked decrease in price of Portland cement in America, the difference in cost between a Portland and a natural-cement base is not so great as formerly.

946. Transverse Slope. A cement walk when built along the side of a street should have a transverse slope of at least $\frac{1}{8}$ of an inch per foot, and preferably $\frac{1}{6}$ or $\frac{1}{4}$ of an inch; but should never have more than $\frac{3}{8}$ of an inch per foot. A slope of $\frac{1}{2}$ an inch per foot gives an unpleasing appearance, and, when the walk is icy, pedestrians slide toward the gutter, particularly on a windy day.

When the walk is laid on comparatively level ground in a public park or on private grounds, it should be crowned to drain the surface. If the center is raised $\frac{1}{8}$ to $\frac{1}{4}$ of an inch per foot of half width, the surface will always be practically dry, provided

it is an inch or more above the adjoining surface, and provided dead grass and leaves are not allowed to wash against the standing grass and form a dam. A crown of $\frac{1}{8}$ inch per foot of half width is ordinarily sufficient to drain the depressions left in troweling.

947. Color of Walk. Ordinarily cement walks have an unpleasant glare, particularly where a considerable area is laid together, as around public buildings, fountains, etc. This glare can be mitigated by coloring the walk. The coloring matter must not contain acids, and must have no effect upon the alkalies of the cement. Dry mineral colors seem to be the only ones that can be used, as apparently all liquid coloring matter destroys the cement. Usually any coloring matter lessens the strength of the mortar, and causes the surface to flake off; and therefore no more should be used than is absolutely necessary, especially of the ochres (§ 948). Ultramarine is an exception to this rule, since a small quantity increases the strength of the mortar, and 30 to 40 per cent may be used without materially decreasing the strength.

Germantown lampblack is more frequently used than any other coloring matter, and gives a bluish gray or stone color of intensity varying with the amount used. It can be had at drug stores in 1-pound packages, and costs about 12 to 15 cents per pound. Four pounds per cubic yard of sand gives a fairly satisfactory result, although twice as much is frequently recommended. Lampblack is light dry stuff, and it is difficult to get it thoroughly incorporated with the mortar. Some contractors add it to the cement, and mix the two by passing them through a sieve; but a better method is to mix the lampblack with the dry sand by turning once or twice, and then to sprinkle the mass and bank it up, and allow it to stand at least over night, when the coloring matter will be uniformly distributed throughout the mass. The lampblack and sand can stand any length of time before being mixed with the cement.

Some contractors color only the surface of the walk instead of the entire wearing coat as above. There are two ways of doing this: 1. The coloring matter is added to a mixture of sand and cement of the same proportions as that used for the wearing coat. This mixture is sprinkled over the wearing coat after it is in place and then the surface is floated and troweled. This treatment is repeated two or three times until the desired shade is

obtained. When this method is employed, the wearing coat must be mixed a little wetter than otherwise, so that the dry colored mortar may be properly worked into the wearing coat. This method of coloring the surface is not so good as the preceding, since the coloring matter is likely ultimately to wear through and leave the walk spotted. 2. Another method of applying the coloring matter is to sift or sprinkle it over the surface, and then to trowel it in. This is a very poor method, since the coloring matter is easily blown away, and the walk is likely to be spotted or to wear so, and also to flake off in places where there is an excess of coloring matter.

948. Almost any color can be produced by the use of the right coloring matter. The following list of colors and coloring matter is frequently quoted.

Color Desired.	Ingredient Used.	Quantity per Bbl. of Cement.
Black	Peroxide of Manganese	48 pounds
Blue	Ultramarine Blue	20 "
Brown	Brown Ochre	24 "
Gray	Lampblack	2 "
Green	Ultramarine Green	24 "
Red, dull	Oxide of Iron	24 "
bright	Pompeian or English Red	24 "
sandstone	Purple Iron Oxide	24 "
Violet	Violet Iron Oxide	24 "
Yellow	Yellow Ochre	24 "

950. Sometimes a very white walk is desired. White can not be produced by adding a coloring matter. Some Portland cements bleach out and make whiter walks than others. To secure a white walk, use white sand or powdered white marble and perfectly clean water, and keep the surface of the walk free from dirt or dirty water. A very white surface can be obtained by using pure white slaked lime and white sand, but the walk will have no durability. Sprinkling the ordinary cement walk frequently and allowing the sun to shine upon it for a few days after it is completed, seems to bleach it.

951. Street Signs. It has been proposed to indicate the names of the streets by inserting colored letters in the cement walk at the corner of the block. This may be done by placing wooden or metal letters of a thickness equal to the wearing coat in the proper position and laying the wearing coat around them, and then removing the letters and filling the space with colored cement-mortar.

952. Slipperiness. Ordinarily cement walks are not slippery, though occasionally one is seen that is somewhat slippery. There is considerable difference of opinion among contractors as to the cause of the slipperiness, some claiming that it is due to too much troweling, others to too rich mortar, and still others to one or another particular brand of cement. Apparently a slippery walk occurs only when the wearing coat is rich in a very finely ground cement, and is troweled excessively long. The long continued troweling seems to work an excess of very fine cement to the surface of the walk. If the sand is coarse and sharp, such a walk will cease to be slippery when the film of neat cement has worn away; but if the sand is very fine, the walk may always be slippery.

"If a cement walk is so hard that one may strike fire with the shoe heel, it is nearly certain to wear slick." Walks made with granite screenings are usually smoother than those made of sand, since the angular fragments of granite are not so easily displaced as the rounded sand grains and consequently the surface is not roughened by the depressions left by the dislodged particles.

953. Precautions. Since cement walks are very common and are often built by inexperienced workmen without adequate supervision or inspection, a summary will be given of some of the precautions to be observed if first class work is desired. 1. Use clean sand, particularly in the wearing coat. 2. Use the same brand of Portland cement in base and top. 3. Thoroughly mix the sand and cement dry. 4. Use a minimum amount of water, i. e., only enough to make the mortar the consistency of moist brown sugar. 5. Mix the mortar and the broken stone until each fragment of stone has mortar adhering to every point of each face. 6. Consolidate the concrete, particularly at the edges, by thorough tamping. 7. Avoid long blocks, and also broken joints. 8. Under no consideration, attempt to place the top coat if there is a film of dirty water on the top of the concrete base. 9. Apply the wearing coat as soon as the base is in position. 10. Tamp the wearing coat or use heavy pressure in troweling it. 11. Finish the surface of each block to a plane, and be very careful that it is not low in the center. 12. Keep the walk damp for several days after it is finished. 13. The thickness of the concrete base and also of the wearing coat should conform to the specification, and each should have the specified proportions of sand and cement.

954. Cement Walk Across Driveway. Cement walks frequently cross private driveways, and often the driveways themselves are paved with what is practically a cement walk, except that the construction may be a little heavier. The surface of the driveway should be roughened to give a good foot-hold for horses. One method of doing this is to form V-shaped grooves, about 1 inch wide and ½ inch deep and 4 inches apart, across

FIG. 160.—CEMENT-WALK GROOVER.

the driveway. These grooves may be made with a tool somewhat like that shown in Fig. 157, page 607, but can be most easily made by the use of the tools hown in Fig. 160. When a cement sidewalk is carried across an unpaved driveway, the foundation and also the walk itself should be made heavier; and in addition the crossing should be widened, the added portion being constructed with an inclined surface to assist the wheels in mounting and to prevent them from crushing the edge of the walk. In the South Side Parks of Chicago, at intersections of unpaved streets and alleys, the edge of the walk is carried down 18 inches

from the surface of the walk to form a curb. This curb or header is 6 inches thick and is faced the same as the surface of the walk, and its upper corner is finished with a radius of 1½ inches.

955. Cost of Cement Walks. *Materials.* One barrel of Portland cement will lay about 35 square feet of walk having a 3-inch concrete base composed of one part cement and two parts of sand, about half of the cement being required for the base and half for the top. If gravel is used instead of sand and broken stone, the above proportions will still be approximately true. One yard of gravel will lay about 80 square feet of concrete base. One yard of sand will make 250 square feet of wearing coat. One yard of cinders will cover about 72 square feet 4 inches thick after being tamped.

Gravel and sand can usually be had at $1.00 per cubic yard, delivered. Cinders cost from 15 to 50 cents per cubic yard at the furnace, and will usually cost 50 cents per cubic yard to haul. Granite chips that will pass a 1-inch mesh and be caught on a ¼-inch mesh will usually cost about $4.00 per ton or about $5.60 per cubic yard (= 2,800 lbs.). Screenings of undecayed granite will usually cost $5.50 per ton or about $7.70 per cubic yard.

956. *Labor.* The amount of labor required to lay cement walks varies greatly with the organization of the gang, and also with the energy and skill of the superintendent. A man can do the excavation for 250 to 300 square feet per day, assuming that the excavation is to be only 10 or 12 inches deep, and assuming that the earth is simply cast to the side, and assuming further that the earth is in good spading condition. Under the conditions assumed above and with wages of common labor at $1.50 for 10 hours, the excavation will cost only about ½ a cent per square foot; but most contractors estimate that under average conditions, it will cost 1 cent per square foot. Wheeling, grading, and tamping the cinders will cost about ½ a cent per square foot. One finisher and five common laborers should on the average lay 800 square feet of walk in 10 hours, exclusive of the preparation of the foundation; but apparently some contractors with 6 men put in 1,200 square feet in 9 hours, while others lay only 600. A well organized gang should lay 100 square feet of walk per man. If common labor receives $1.50 per day, a form setter will receive $2.00, and a finisher $3.50 or $4.00.

957. *Total Cost.* The following represents the average experience of a prominent contractor in Central Illinois, for a walk 5 feet wide having a concrete base 3 inches thick composed of one part cement and six parts of gravel and having a wearing coat 1 inch thick composed of one part cement and two parts of sand.

Items.	Cost. Cts. per Sq. Ft.
Portland cement at $2 75 per bbl	8.1
Cinders,—6 inches at 75 cents per cu yd	1.0
Gravel at 80 cents per cu yd	1.0
Labor,—excavating foundation	1.0
placing cinders	0.5
setting forms	0.2
mixing and placing concrete for base	0.6
mixing and placing wearing coat	0.2
troweling and finishing	0.5
Teaming,—hauling forms and tools	0.2
Tools and lumber, 6 per cent	0.7
Total cost exclusive of superintendence, guarantee, and profits	14.0

958. **Cinder Walks.** Cinders are sometimes employed for the surface of foot-ways; but usually they are more expensive than gravel, and are always much less satisfactory. They are dusty during dry weather and muddy during wet weather and when the frost is going out of the ground. The cinders track into buildings, where they are very destructive of floors and are otherwise annoying. Cinders easily grind up under traffic, and blow away; and therefore new material must be added continually. They are light and easily washed away; and consequently after every rain storm more or less repairs are necessary, to say nothing of removing the cinders from catch basins.

To make a cinder walk the foundation should be excavated at least 6 inches deep, and more if the soil is retentive. Then a layer of cinders 6 inches deep should be put into the trench, using care to cover deeply the large clinkers. The best cinders for walks are those made at a power plant, since they are more free from ashes than those in stoves and household furnaces (see § 922). The cinders should be flooded and tamped, to pack the finer particles about the coarser ones. The surface should have a crown, and

there should be a small gutter at the edge to preserve a line between the walk and the lawn

959. GRAVEL WALKS. Gravel is employed for walks chiefly in parks because its natural color usually harmonizes well with that of grass and the foliage of trees and shrubs, and also because a gravel walk is not as hard and stiff in appearance as one of asphalt or cement. When there is a large amount of travel, or where the gravel walks are not well constructed or properly maintained, it may be desirable to construct asphalt or cement walks to prevent disfiguring foot-paths in the turf at the edge of the walk and to obviate the use of unsightly wire or chain fences.

To construct a gravel walk on a sandy subsoil, excavate a trench 4 or 5 inches below the lawn surface, and make the subgrade parallel to the surface of the proposed walk; and then lay 3 or 4 inches of crushed stone or bonding gravel, no piece or pebble of which is more than 1 inch in greatest dimension. If gravel is used, it should not have too much clay in it, or the clay will work through the surfacing material and make the walk muddy and sticky; and the gravel should not contain too little binding material, or the walk, particularly at the crown, will be loose and stony, as the larger pebbles of the foundation will work to the surface of the walk owing to the binding material's being washed out. If the subsoil is clay, excavate the trench, say, 8 inches deep, and lay 5 inches of cinders reasonably free from ashes; and then upon this lay $2\frac{1}{2}$ inches of crushed stone or binding gravel. In either case, the crushed stone or gravel should be rolled with a 5-ton steam roller, substantially as for a gravel road (§ 254), or for a broken-stone road (§ 341–45).

The top of the foundation should be made exactly parallel with the surface of the finished walk.

The wearing surface should consist of from $\frac{1}{4}$ to $\frac{1}{2}$ inch of fine torpedo gravel, i. e., sand having grains from $\frac{1}{8}$ to $\frac{1}{4}$ inch in greatest dimension. The surface of the walk should have a crown of, say, 2 or 3 per cent of its width; but if the crown is too great, the torpedo sand will be washed into the gutter. The edges of the gravel surface should be depressed about $1\frac{1}{2}$ inches below the adjoining lawn.

Paved gutters are very undesirable, but where the walk is on

a steep grade they are a necessity. A neat and durable gutter may be formed of small cobble stones. If the slope of the adjoining ground is such that the surface water is likely to flow onto the walk, a sod gutter should be formed on the upper side of the walk. This is done by sinking the turf alongside and parallel to the walk, to form a broad shallow depression. This gutter should have no low places which will catch and retain silt. These sod gutters should have frequent inlets into an underground drain.

960. Macadam Walks. Crushed-stone walks are constructed in substantially the same way as described above for gravel walks, except that the surface is covered with stone screenings instead of torpedo sand. The fragments should not be more than $\frac{1}{8}$ inch in greatest dimension if the stone is hard; but if it is soft, the pieces may vary from $\frac{1}{8}$ to $\frac{1}{4}$ inch in diameter. A surface of crushed limestone is pleasant to walk upon; but its color is trying on the eyes, and does not harmonize well with the color of the grass and the foliage of trees and shrubs. Crushed granite makes a durable walk, and usually has a satisfactory color; but the particles are so sharp as speedily to cut out thin-soled shoes. A walk surfaced with crushed stone is less satisfactory both to walk upon and in appearance than one having a surface of fine gravel.

961. Plank Walks. In the past plank sidewalks have been very common, but owing to the increasing cost of lumber and to the introduction of bricks for walks, they are much less common now than formerly. There is great variety in the forms of construction employed; but as a rule the design is poor, little or no attention being given to the conditions necessary to secure durability. However, the standard plank sidewalk adopted by the City of Omaha, Neb., in 1899, is an exception. Fig. 161, page 619, shows three views of the standard 6-foot walk. The specifications for plank walks in Omaha are as follows: *

"Plank walks shall be built in accordance with the standard general plans hereto attached [Fig. 161], to the exact height and line given by the engineer. The stringers shall not be less than 12 feet long, except when necessary at the end of the walk, and shall break joints and be placed on bricks not more than 6 feet apart,

* By courtesy of Andrew Rosewater, City Engineer.

resting upon a solid foundation. The stringers shall be cut square at the ends,* and shall be closely fitted at the joints; and each joint shall be toe-nailed with two nails 4 inches long. This part of the work shall be accepted by the City Engineer before the planking is laid.

"All lumber shall be white pine, square edged, and shall grade

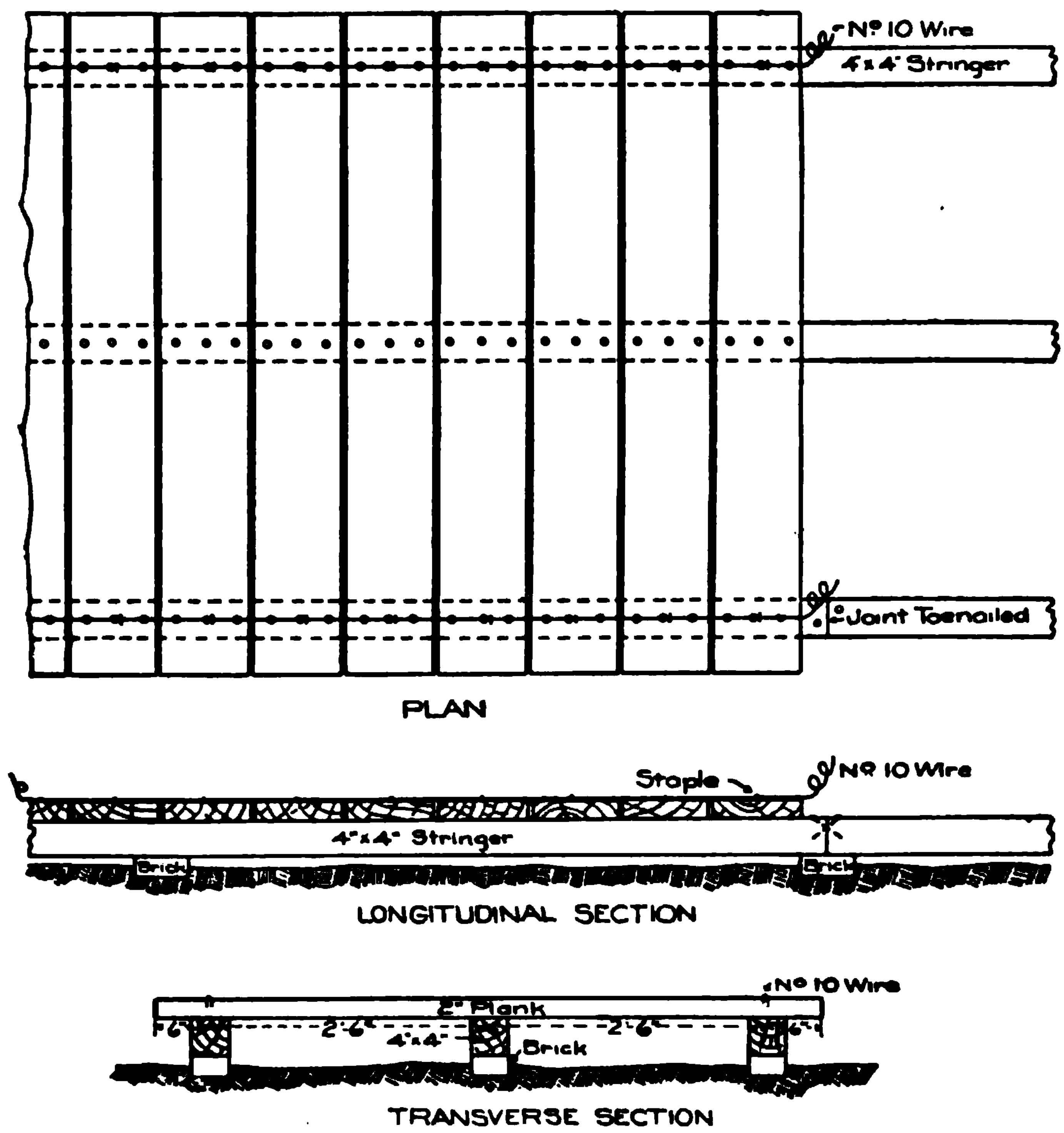

FIG. 161.—OMAHA PLANK SIDEWALK.

as No. 1. The planks shall have a width of not less than 8 inches, nor more than 12 inches, a uniform thickness of not less than 2 inches, and a length equal to the full width of the walk. The planks must be laid with a ½-inch air space between them, and there shall be a space of at least 4 inches between them and

* The Cincinnati specifications require the stringers to be joined with a 3-inch half-lap splice which is spiked.

the ground. The planks shall be nailed at each intersection with two nails for 8-inch planks and with three nails for planks more than 8 inches wide. The nails shall be 4 inches long, and shall be either cut nails weighing twenty to the pound or wire nails weighing thirty to the pound, with heads $\frac{7}{16}$ inch in diameter. The nails shall be driven in the center of the stringer, and the heads shall be driven $\frac{1}{4}$ inch below the surface of the plank. Any lumber split or otherwise injured in construction shall be removed and be re-placed with good material.

"At each edge of the walk shall be securely fastened a No. 10 galvanized iron wire, with a wire staple in each end of each plank."

962. Cost. In Omaha in 1899, plank cost $19 per thousand feet board measure, and sills $22; labor exclusive of excavating and grading, $11 to $12 per thousand feet of lumber; wire and stapling $1\frac{1}{2}$ to 2 cents per lineal foot of walk. A 6-foot walk complete cost 39 to 40 cents per lineal foot.

963. Stone Sidewalks. One of the earliest methods of paving foot-ways was to cover them with natural stone flagging, and such walks are still very common where flagstones of suitable size may be readily obtained. If hard and smooth and well laid, natural stone slabs make a fairly durable and satisfactory walk. A walk made of split flagstones is ordinarily a little smoother than one made of brick, but is not so smooth as a cement walk. If the stone is tool-dressed, it may be nearly or quite as smooth as a cement walk.

Granite, limestone, and sandstone are often used. The kind of stone to be employed in any particular locality will depend upon the availability of the stone and the service required of it.

On business streets where large blocks are required to span coal or storage vaults under the sidewalk, and where large loads are likely to be transported over it from the curb to the building, granite is generally used; but it is expensive, and wears slippery, so that when laid upon a crowded business street its surface must frequently be roughened to prevent its becoming dangerously slippery. It is largely used in the eastern cities where cheap water-transportation can be had. Sandstone, when sufficiently hard to resist abrasion satisfactorily, makes the best flagstones. since its gritty nature prevents it from wearing slippery. In and around

New York city, Hudson River bluestone, a variety of sandstone (see § 517), is much used for this purpose. In the west, Bedford (Ind.) limestone is employed, although it chips and spalls too easy for the best results.

On residence streets, the flagstones are laid upon the natural soil or upon a foundation of cinders or gravel. If laid directly upon the soil, the stones are likely to become displaced by the action of frost; and therefore they should be laid upon a sand cushion resting on a well-rammed bed of porous gravel or cinders, and should be carefully bedded so as to preserve a uniform surface.

The flagstones should be as large as is consistent with economy, since there will then be fewer joints and less likelihood of the surface of the walk becoming uneven. On the other hand, if the size be made too great, the cost will be excessive, as it is more expensive to quarry and to transport large blocks than small ones, and there is also more likelihood of breakage. As a rule the stones should not contain less than 15 or 16 square feet, although blocks 1½ by 2½ feet are not uncommon. The thickness of the flagstones for walks on residence streets laid upon a solid foundation usually varies from 2 to 3 inches. The edges should be cut straight and square, and smooth enough to lay thin joints. The stones should be laid with their length across the walk to prevent pedestrians from walking along the middle of a row of stones and wearing them hollow; and the stones should break joints, so as to prevent continuous longitudinal joints.

964. Crossing Stones. Foot-ways of flagstones are usually provided across pavements which are rough to walk upon or are likely to be muddy. These crossings consist of stones 12 to 14 inches wide laid in rows across the street, the rows being 6 or 8 inches apart, and the stones 6 or 8 inches thick, and 3 to 6 feet long.

The ends of the stones should be cut on a bevel so that there may be no joints in the direction of the travel. The best arrangement of the end joints is shown in Fig. 162, page 622. Not infrequently the joints all slope toward one end of the crossing, in which case some of them are parallel to the traffic going around the corner, and hence this arrangement is not so good as the one shown in Fig. 162. It is usually specified that the ends shall be dressed to lay ¼-inch joints for the full thickness of the stone, and

that the upper surface shall be dressed so as to have no depressions of more than ½ inch. The stones should be firmly bedded upon the foundation.

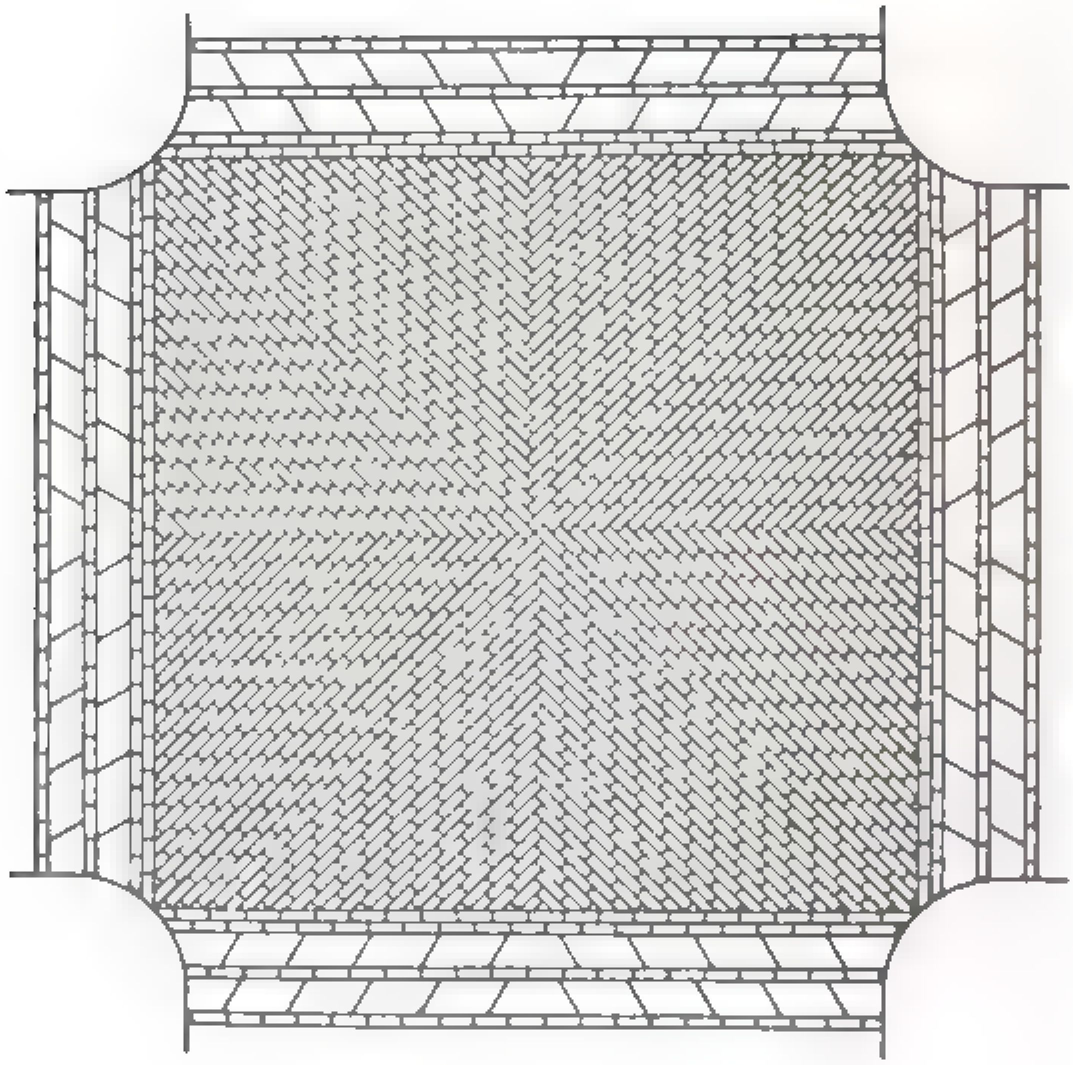

FIG. 161.—STONE CROSS-WALKS.

965. Cost. The catalogue price, per square foot, of Potsdam sandstone sidewalk flags 2 inches thick, f. o b. cars at Potsdam, N. Y., is as follows:

2 feet wide......	9 cts per sq. ft	6 feet wide......	25 cts. per sq. ft
3 " "	12 " " " "	7 " "	32 " " " "
4 " "	15 " " " "	8 " "	40 " " " "
5 " "	20 " " " "		

and the cost price per lineal foot of crossing stones at the same place is as follows:

10 inches wide...........	12 cents	16 inches wide...........	20 cents
12 " "	15 "	18 " "	24 "
14 " "	17 "	24 " "	30 "

In New York city, Hudson River bluestone sidewalk flags cost from 16 to 22 cents per square foot delivered on the street, and the cost of laying is about 2½ to 3 cents per square foot. In Boston, Hudson River bluestone crossings cost 29 to 30 cents per square foot f. o. b. the wharf, and cost about 2 cents to haul to the street.

966. TAR WALKS. Foot-way pavements made of concrete in which coal tar is the binding material have been widely used, particularly in England. Some tar pavements have given entirely satisfactory results; but usually they have been very unsatisfactory, wearing rapidly and becoming unpleasantly soft in hot weather. Tar walks have practically been abandoned.

Numerous methods were tried, differing from each other chiefly in the materials mixed with the tar. Ashes, sand and gravel, or cinders were generally preferred. The best construction consisted of a 4-inch foundation of dry pebbles thoroughly coated with tar and compacted while hot, and a 1-inch wearing coat composed of dry screened sand saturated with tar and rolled into place while hot. This pavement usually costs 5 to 6 cents per square foot.

967. COMPARISON OF WALKS. A walk should be smooth but not slippery, should dry quickly after a rain, should be durable and not easy to get out of repair, and should be low in first cost. In the order of smoothness the principal materials rank about as follows: asphalt and cement, stone slabs, brick, plank, gravel and macadam. In the readiness with which they dry after a rain the materials rank about as follows: asphalt and cement, stone slabs, bricks, plank, macadam, gravel. In durability they rank about as follows: brick, cement, stone, gravel and macadam, asphalt, plank. The cost varies so much with the locality and the form of construction that it is impossible to give their rank except in a particular case. Cement and brick seem to be the general favorites, the first where a first class walk is desired and the second where a cheap walk is required. The roots damage brick walks much less than those made of cement.

CHAPTER XX.

BICYCLE PATHS AND RACE TRACKS.

ART. 1. BICYCLE PATHS.

969. A bicycle in the eyes of the law is a vehicle and is entitled to travel upon the public highways subject to similar rights of other travelers; and the bicycle has come into such general use that a reasonable provision for this class of traffic should receive the careful consideration of all officials charged with the care of public highways. It is frequently claimed that the bicycles outnumber other vehicles six to one; but this can be hardly true for the whole country, although it may be true in the cities. It is certainly true that the use of the wheel has extended to every profession and occupation in life, and that the bicycle has become a familiar object in every civilized land. The great number of men and women who use the bicycle as a conveyance both for business and for pleasure are rightly entitled to be placed upon an equal footing with pedestrians who use the sidewalks and with those who ride in other vehicles upon the carriage ways.

The construction of cycle roads will be considered under two heads: City Bicycle Ways, and Country Bicycle Paths.

970. CITY BICYCLE WAYS. The wheel being recognized as a proper conveyance and as entitled to the use of the street under reasonable restrictions, the question arises as to what portion of the street the wheelman shall use and whether any special construction is required for their accommodation.

In business districts and in residence districts having fairly smooth pavements, it seems reasonable to confine the bicycle traffic to the carriage way; but on residence streets where the pedestrian travel is light and the carriage way is not surfaced with a material

which is suitable for bicycle travel, the wheelmen should be permitted to use the sidewalks under proper rules regulating the speed, particularly in meeting and passing pedestrians. However, there are main avenues of travel to the business district and to parks, ball grounds, summer resorts, etc., where neither the carriage ways nor the sidewalks afford reasonable facilities for the wheelman and where the volume of bicycle travel for both business and pleasure is sufficient to require a special construction for its proper accommodation. Some cities lay smooth pavements on leading thoroughfares for the accommodation of wheelmen, while others construct special cycle ways on unpaved streets, and sometimes at the sides of paved streets having a dense vehicular traffic. In some cases special cycle ways are constructed at the expense of the city and in other cases by private contributions of wheelmen.

Where there is any considerable amount of bicycle traffic, it is true economy to set apart a certain portion of the street for the use of the wheelmen, since the traffic can not, with safety to pedestrians, be accommodated upon the sidewalks, and since it is much cheaper to construct a pavement suitable for a cycle carrying 100 pounds on a rubber tire than to construct a pavement for a truck concentrating perhaps 2,000 pounds upon a steel-tire. Further, cycle ways are much cheaper to construct than sidewalks, often costing one fourth or one fifth as much.

971. Location. Some cities have allotted a strip in the middle of the street for the use of wheelmen, but the result has not been satisfactory owing to the difficulty of keeping teamsters from trespassing thereon. The cycle way should be either on the edge of the roadway next to the curb, or in the parking between the curb and the shade trees, the former probably being the better on an unpaved street and the latter on a paved street (see § 468).

972. Width. The width should depend upon the amount of cycle traffic, and varies from 3 to 16 feet, but is seldom less than 4 feet for city paths. One wheel can pass another at speed on a 4-foot path, but not safely upon a narrower path.

973. Materials. The wearing-surface may consist of a layer of sand, gravel, cinders, or crushed-stone screenings on an earth bed, or it may consist of plank laid upon timber mud-sills, or it may be a strip of sheet asphalt laid upon a rough stone-block pavement. A

layer of screened black cinders (§ 922) about 1 inch thick on a firm foundation makes a fairly good cycle path; and a layer 3 to 6 inches thick, if sprinkled and rolled or tamped, makes an excellent surface. The chief advantages of cinders are that they are usually cheap, are always dry, and give a fairly firm surface; while the principal disadvantages of cinders are (1) that they are not durable, since in dry weather they powder up and blow away, and in wet weather they wash off, and (2) that the sharp angular particles are destructive of bicycle tires.

A mere sprinkling of coarse sand on a bed of hard and well drained earth makes a fine surface, but one that is easily damaged by the feet of horses and cattle or by the wheels of ordinary vehicles. A layer of cementing gravel ½ to 1 inch thick, upon a well drained and thoroughly consolidated earth bed makes a durable and pleasing bicycle road. The largest pebbles should not be more than ¼ to ⅜ of an inch in longest dimension, and the mass should contain sufficient binding material (see § 345) to keep the surface firm and hard. If the gravel contains much clay, the surface will be sticky and muddy during a wet time.

The best cycle ways are constructed much the same as first-class broken-stone roads, except that the layers need not be as thick and do not require as much rolling. The surface should be finished with a layer of stone screenings ¼ to ½ inch thick, the size ranging from ¼ inch to dust.

In localities where lumber is cheap, it is common to construct cycle ways of plank very much as sidewalks are made—see § 976 and § 977.

974. Grade. For obvious reasons, the grade of the cycle ways now under consideration must be practically the same as that of the street pavements (see § 471 and § 479).

975. Cross Section. Since the cycle way is usually comparatively narrow it is immaterial whether its surface be slightly crowning or have a small fall toward only one side; but the surface of the way should be a little above the adjoining ground to afford good surface drainage.

976. Examples. Fig. 163, page 627, shows five plans that have been used in constructing city cycle ways. Plans *A*, *B*, and *C* are constructed of wood; and *D* and *E* are constructed of gravel.

or broken stone. The curb on the right-hand side of Plan *D* is supported by being spiked to posts firmly set into the ground.

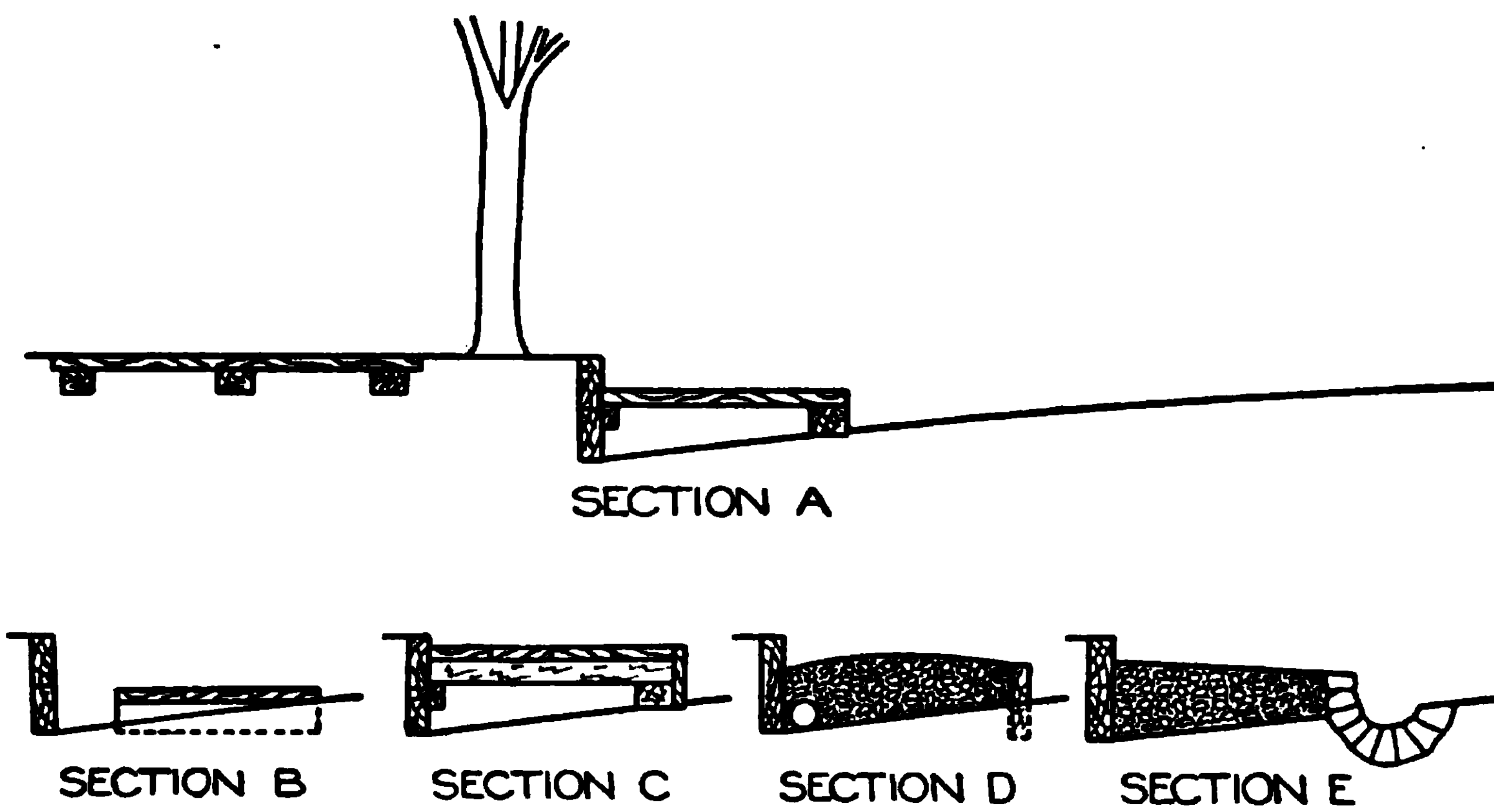

FIG. 163.—PLANS FOR CITY BICYCLE PATHS.

977. Fig. 164, page 628, shows the four standard forms of cycle ways employed by the City of Portland, Oregon. The following are the specifications:*

"Plan *A* is built of timber and consists of mud sills, 4×6 inches, placed at right angles to the path, 4 feet apart center to center. Where the side slope of the street surface is flat, the sills will be laid broad-side down; but where the side slope is steep, they will be set on edge. The sills must be bedded solidly in their places, and must be level and at such an elevation that the surface water from the street can pass under the planks to the gutter. Along the outer edge of the cycle way a slight ditch must be excavated. The covering will consist of five planks, 2×12 inches, sized to a thickness, in lengths not less than 16 feet. They must be laid close together and break joints not less than 4 feet. Each plank must be nailed to each mud sill with a spike in each edge of the plank at the intermediate sills and three spikes at each end, the spikes being 6 inches long. The plank surface will generally be placed one foot from the curb, and on the same grade as it. All the labor of building the cycle way must be done in a good and workmanship manner.

"Plan *B* is built without timber except where drain boxes are necessary. The center of the shallow ditch on the roadway-side of the cycle way will be 6 feet from the curb. The material from this ditch will be thrown into the embankment; and earth, gravel or crushed rock will be added sufficient to raise the embankment 8 inches above the normal surface of the street.

* By courtesy of William B. Chase, City Engineer.

The cycle way will be slightly crowned. The side slopes must be rammed until they are hard and smooth; and the top of the path must be rammed until it is firm and hard. The top will then be covered with a 1-inch layer of cementing-gravel screenings * or crushed-rock screenings, which will be rolled until hard and smooth. The gutter next to the curb must not be less than 6 inches wide at the bottom, and must be smooth and clean.

"Plan *C* is an earth cycle way with plank curb. This path will be built by setting a 4×14-inch curb 5½ feet from the sidewalk curb. The top of the cycle-way curb will be 2 inches below the top of the sidewalk curb and will be set in the same manner. The joints in the curb will be secured by spiking a

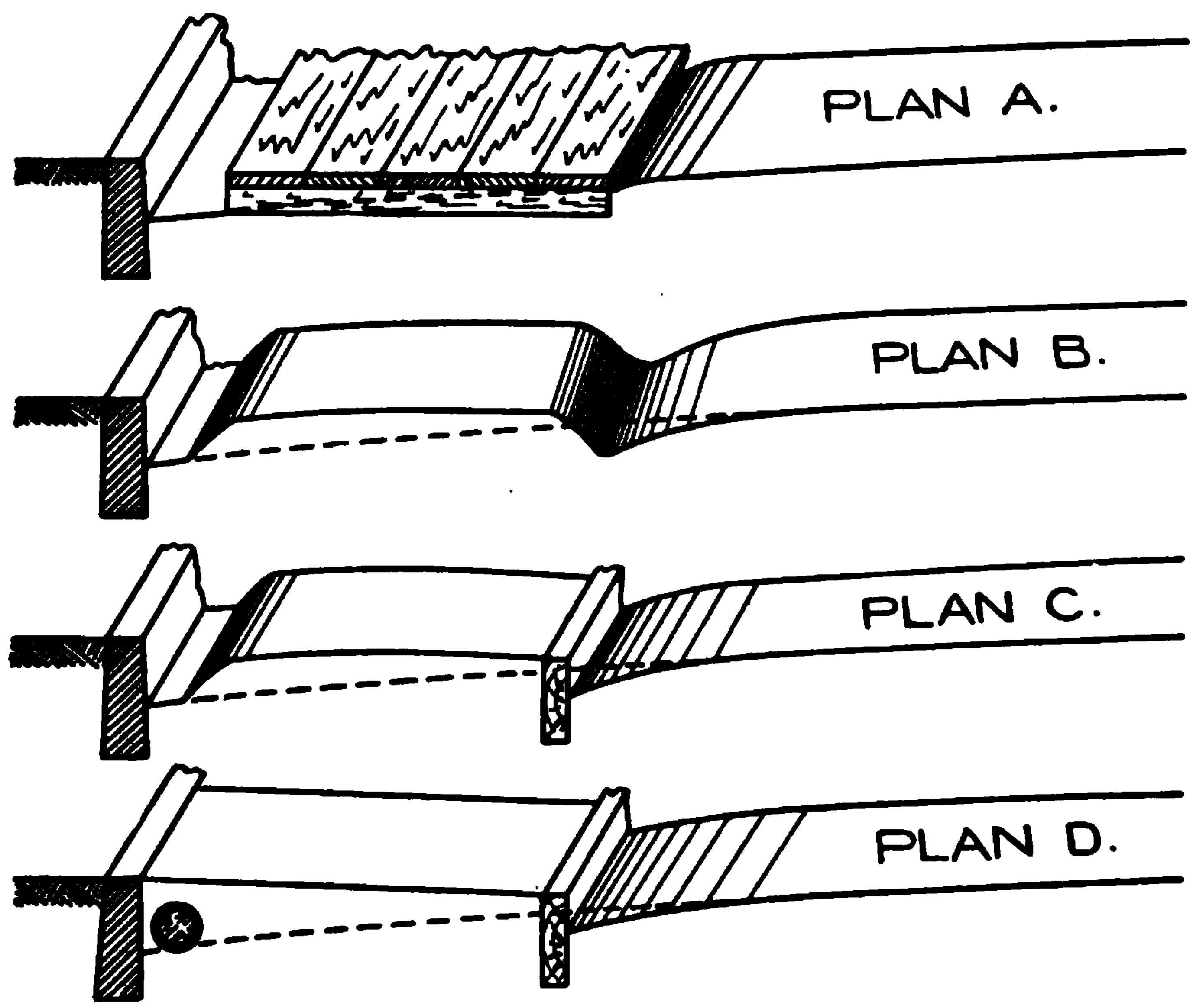

FIG. 164.—PORTLAND CITY-BICYCLE PATHS.

piece of 3×12-inch plank 4 feet long on the inside of the curb, the top of the splicing piece to be 2 inches below the top of the curb. On the outside of the cycle-way curb a ditch will be excavated approximately 6 inches below the top of the curb, the material from the ditch being thrown on the path. After the curb is securely set and tamped, an embankment will be formed of earth, gravel, or of crushed rock to a height at the center of the path of approximately 8 inches above the normal surface of the street. The gutter next to the sidewalk curb will be 6 inches wide at the bottom, and the

* Gravel screenings having high cementing qualities were used, and it is recognized that the layer is thicker than is necessary; but the material was plentiful, and was used liberally.

slope will be flat enough to be stable. The embankment will be rammed or rolled until it is solid. The wearing surface will be a layer of cementing-gravel screenings or crushed-rock screenings, which shall be rolled or rammed until hard.

"Plan *D* is the same as Plan *C* except in the matter of the open gutter next to the sidewalk curb. The cycle-way curb is a 4×14-inch plank set 5 feet from the sidewalk curb with its top edge 1½ inches below the top of the sidewalk curb. The top of the cycle way will be finished with a downward slope of 1½ inches toward the carriage way. Where considered necessary by the City Engineer, a tile drain must be placed along the curb as shown in the Fig. 164; and all house rain-water pipes discharging into the ditch must be covered with earth.

"Crossings will generally be 5 feet wide, and will be constructed of 3×12-inch fir planks laid on 4×4-inch mud sills,—the same as is used for sidewalk crossings. For the arrangement of cycle-way street-crossings, see Fig. 165.

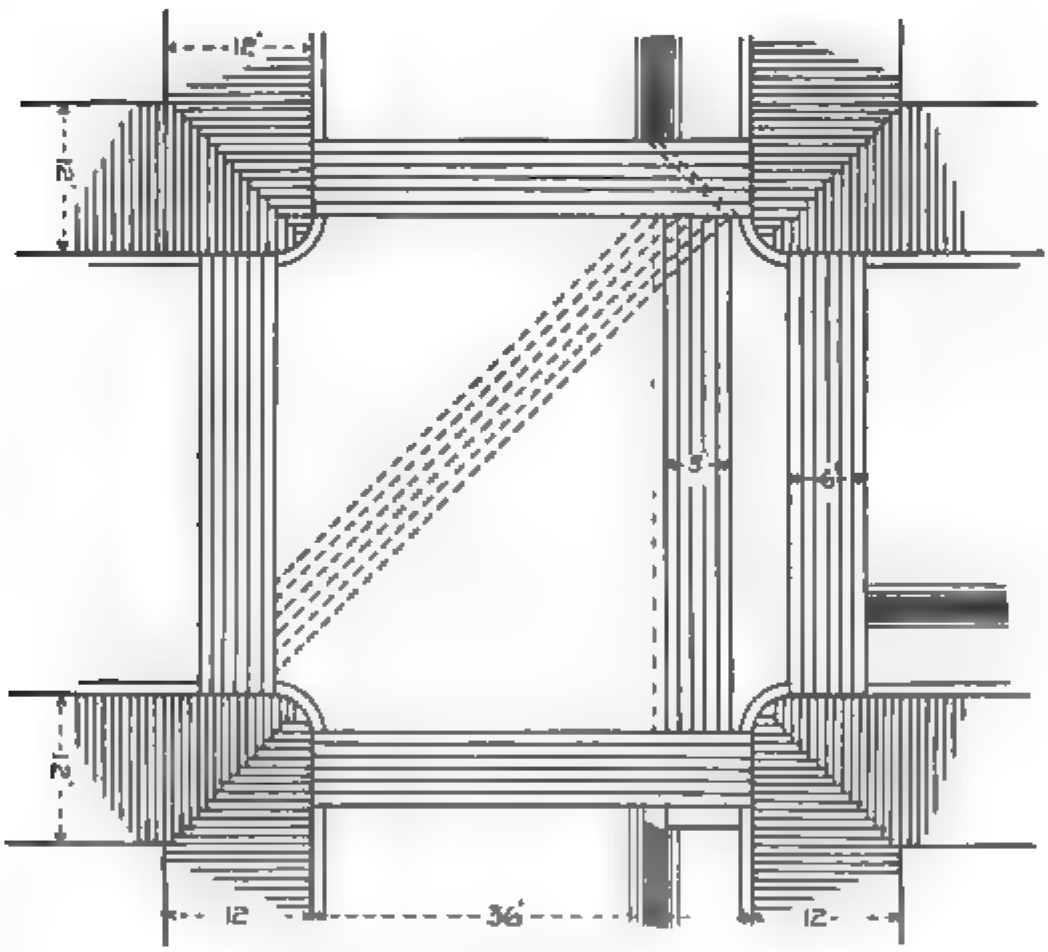

FIG. 165.—PORTLAND CYCLE-PATH CROSSING.

"At the lower corner of the blocks, the water from the cycle-way ditch must be carried to the ditch next to the sidewalk curb through a wooden box constructed alongside of the cross walk and having its top flush with the surface of the walk. The drain box must not be less than 6×10 inches inside, and must be made of 3×12-inch plank."

978. For a few particulars concerning cycle ways constructed in St. Paul, Minn., see § 980.

979. Cost. The cost of a city cycle way will vary greatly with the style of construction, the cost of materials and labor, etc. The following examples are of interest.

980. *St. Paul.* In St. Paul, Minn., in 1897, about 12 miles of cycle ways were built, the cost and the method of construction being as follows: * A cycle way 10 feet wide consisting of 4 inches of coal cinders at the center and 2 inches at the side, and covered with a ½-inch layer of sand and loam or clay mixed, having a crown of 4 inches, with broken-stone street crossings, built where the only grading consisted in removing the sod, cost $500 per mile, common labor being 18¾ cents per hour, teams 37½ cents per hour, and cinders 40 cents per cubic yard delivered. An 8-foot path consisting of cinders 3 inches deep at the center and 2 inches at the sides, cost $250 per mile, labor being 15 cents per hour, teams 30 cents per hour, and cinders 25 cents per cubic yard delivered. A 3-foot cinder path along a graded street cost $165 per mile.

981. *Brooklyn.* In Brooklyn, N. Y., in 1895, a 12-foot cycle way from Prospect Park to Coney Island, constructed of broken limestone, cost about $3,250 per mile.

982. *Rochester.* At Rochester, N. Y., a 16-foot cycle way having a 4-inch limestone base and a 2-inch trap top, cost practically $10,000 per mile, exclusive of engineering and inspection, labor being $1.50 for 8 hours and teams $3.50 for 8 hours.

983. COUNTRY BICYCLE PATHS. As a rule, country cycle paths are chiefly for pleasure riding, and the money available for their construction is limited; and consequently the severest economy must be employed. A country cycle path may be anything from a narrow strip of turf worn smooth by the passage of wheels or pedestrians to a broad and carefully constructed roadway.

984. Location. Country cycle paths are usually located at the side of the public highway, in the West at least, between the side ditch and the property line (see § 88); and in any case there should be a ditch between the bicycle path and the carriage way to prevent teamsters from trespassing upon the former.

* L. W. Rundlett, City Engineer, in Proc. Amer. Soc. of Municipal Improvements, Vol. 4, p. 323.

985. Width. Length is more important than width, and consequently the path should be made no wider than is necessary to accommodate the travel. A cyclist touring alone, or several riding in single file, may ride swiftly and comfortably on a path only 10 or 12 inches wide. Unless the travel is considerable, a width from 3 to 4 feet is abundant. One rider can safely pass another at speed upon a path 4 feet wide.

986. Grade. If possible the grades should be reduced to 5 per cent or less, as a steeper grade can not be ascended without extreme effort and is liable to cause accidents in descending. A 2 per cent grade can be ascended with comparative ease and be descended with but little effort and without serious danger.

987. Cross Section. The surface of the bicycle path should be raised above the general natural surface to afford drainage. Usually the excavation of a slight ditch on each side of the path will furnish material sufficient for this purpose. The surface should have a slight crown, that is, should be a little higher in the center than at the sides. On level dry ground it is sufficient to have an elevation of 4 inches at the center and 2 inches at the sides where the surface of the path begins to slope abruptly to the natural surface. In low wet places it may be necessary to throw up a low embankment upon which to construct the path; and on a side hill it is necessary to provide ditches of sufficient capacity to carry away the storm water and to prevent it from coursing down the middle of the cycle path. If the side hill is steep in a direction transverse to the path, it will be necessary to construct a catch-water drain (see § 116) and to build culverts under the path at intervals, to prevent the storm water from flowing over the path.

988. Construction. For a discussion of the various materials employed in constructing cycle paths, see § 973.

In some cases the construction consists in simply cutting a strip of grass 10 or 12 inches wide along the location selected, to indicate the line of the path and to confine the travel, leaving the passing wheels to make a smooth surface. In other cases a path is made by turning a furrow with a plow and raking down the loosened earth at one side of the furrow to form a level surface for the passage of the wheels, which in time will compact the earth and make it hard and smooth.

A more elaborate construction consists in removing the sod and spreading a layer of cinders 3 or 4 inches thick. Cycle paths are not subjected to heavy loads, and hence do not require a carefully prepared foundation; but if the natural soil is loose and porous, it is better and more economical of the surfacing material to roll the subgrade before applying the cinders. All grass, weeds, loose roots, etc., should be removed from the subgrade before rolling it. The cinders should be sprinkled and then rolled with a roller weighing not less than 20 pounds per linear inch of face. The rolling is usually done with a hand roller.

989. *Cost.* Fairly good cycle paths have frequently been constructed for $20 per mile by leveling off the rough places and applying a thin coat of cinders where most needed. Where there is not much grading required, a cinder surface 2 to 3 feet wide will cost about $100 per mile.

In St. Paul, Minn., in 1897, a 6-foot cycle path consisting of cinders 3 inches deep at the center and 2 inches at the side, covered with about ½ inch of clay or loam and a coating of coarse sand, constructed along a country road where the cinders were hauled an average of 1½ miles, cost $200 per mile.*

990. Maintenance. The work of maintenance depends somewhat upon the nature of the material of which the surface is composed; but usually consists in (1) repairing damages from storm water and trespassers, (2) cutting out weeds, particularly at the edge of the path, and lining up the side to give a neater appearance, (3) raking and rolling the surface of the path, (4) adding a layer of cinders or gravel where necessary. The above repairs of a cinder path cost about $25 to $30 per mile, for each time over the path, which is usually once per year.

ART. 2. BICYCLE-RACE TRACKS.†

991. With the general introduction of bicycles came a relatively small class of people who choose bicycle racing as a recreation or as a profession. From these riders came a demand for tracks built

* Proc. Amer. Soc. of Municipal Immprovements, Vol. 4, p. 323.

† This article is an abstract of the thesis of Horatio Weber Baker, the author's son and student, presented for the Degree of Bachelor of Science in Civil Engineering, University of Illinois, June, 1901. Manuscript in the University Library.

especially for bicycle racing. Although bicycle racing is attracting but little attention at present, it may not be amiss to consider briefly the theory and the practice of bicycle race-track construction.

The design of a track will be considered under three heads: 1, the ground plan; 2, the banking or super-elevation of the outer edge; and 3, the material used in the constuction.

992. GROUND PLAN. The following principles must be borne in mind in designing the ground plan of a bicycle race-track.

1. The length and the form of the track will depend upon the size and the shape of the area available.

2. Large tracks are expensive to construct, and do not afford the spectators as good a view of the races as smaller tracks. Very small tracks are objectionable because of the sharp curvature and consequent high banking required.

3. For convenience it is desirable that the length of the track shall be an aliquot part of a mile.*

4. The field should not be so wide that the spectators are unable to see easily all parts of the race.

5. It is desirable that there should be enough straight track upon which to start the race.

6. The curves should be of such form that the rider experiences no lurch due to a change of direction in following the curve.

7. On curves a super-elevation of the outer edge is required, while on tangents none is required; and since this super-elevation can not be effected instantly, a varying curvature should be used to permit the joining of the flat tangents with the fully-banked curves.

993. The conditions which best meet the first four requirements can be determined only by experience, while the conditions meeting the remainder can be determined only by mathematical analysis. It is proposed to describe the more noted tracks with a view of determining the present status of the best practice, and then to design a track which shall fully meet all of the above requirements.

994. Present Practice. The first tracks were very crudely laid out. For example, it is stated that the curves of one of the earliest tracks in this country, the half-mile track at Hampden

* The length of a bicycle track is measured on a line, called the pole line or pole, 18 inches from the inner edge of the track.

Park, Springfield, Mass., were located by running a bicycle over the ground and staking out the trail. Most of the early tracks were semicircles connected by tangents. Among these are the ones at Waltham, Mass., and Louisville, Ky. Each is one third of a mile in length with semicircles of 150 feet radius and tangents 409 feet long. These tracks have each held many world's records, and were for a time very popular.

The Charles River track, Boston, Mass., is one third of a mile in length, the circular curves being joined to the tangents by easement curves consisting of compound circular arcs. This track is a later design by the designer of the Waltham track, and may be considered as proving, in the mind of the designer at least, the importance of joining the tangents and the curves by arcs of varying radii.

The track at Manhattan Beach, Long Island, N. Y., constructed in 1896,* seems to have been the first attempt to meet scientifically requirements 6 and 7 of § 992. This track is one third of a mile in length, and consists of two tangents connected by "elliptical curves" to circular arcs—see Fig. 166, page 635. Apparently the "elliptical curve," *A B*, consists of a series of nine circular arcs, each 6° long, having radii ranging in length from 144 to 212 feet. The circular arc, *B C*, is 38° 17′ long, and has a radius of 136 feet. The tangents are 373.47 feet long, the "elliptical curves" 162.4 feet, and the circular arcs 181.76 feet. The track is 26.5 feet wide, except the home-stretch, which is 40 feet,—the widest track in this country.

In 1896 a one-half mile track was constructed by the West Park Board in Garfield Park, Chicago.† Fig. 167, page 636, shows the ground plan of this track. The tangents are 376.5 feet long and are connected by semicircles having a radius of 300.32 feet. The width is 25 feet, except upon the home-stretch, where it is 35 feet. The widening of the home-stretch was accomplished by moving the center of the semicicular arc for the outside of the track 10 feet toward the home-stretch.

In 1897 a quarter-mile track was constructed at Racine, Wis.,

* *Engineering News*, Vol. 35, p. 188–89.

† *Jour. Western Society of Engineers*, Vol. IV., p. 224–25.

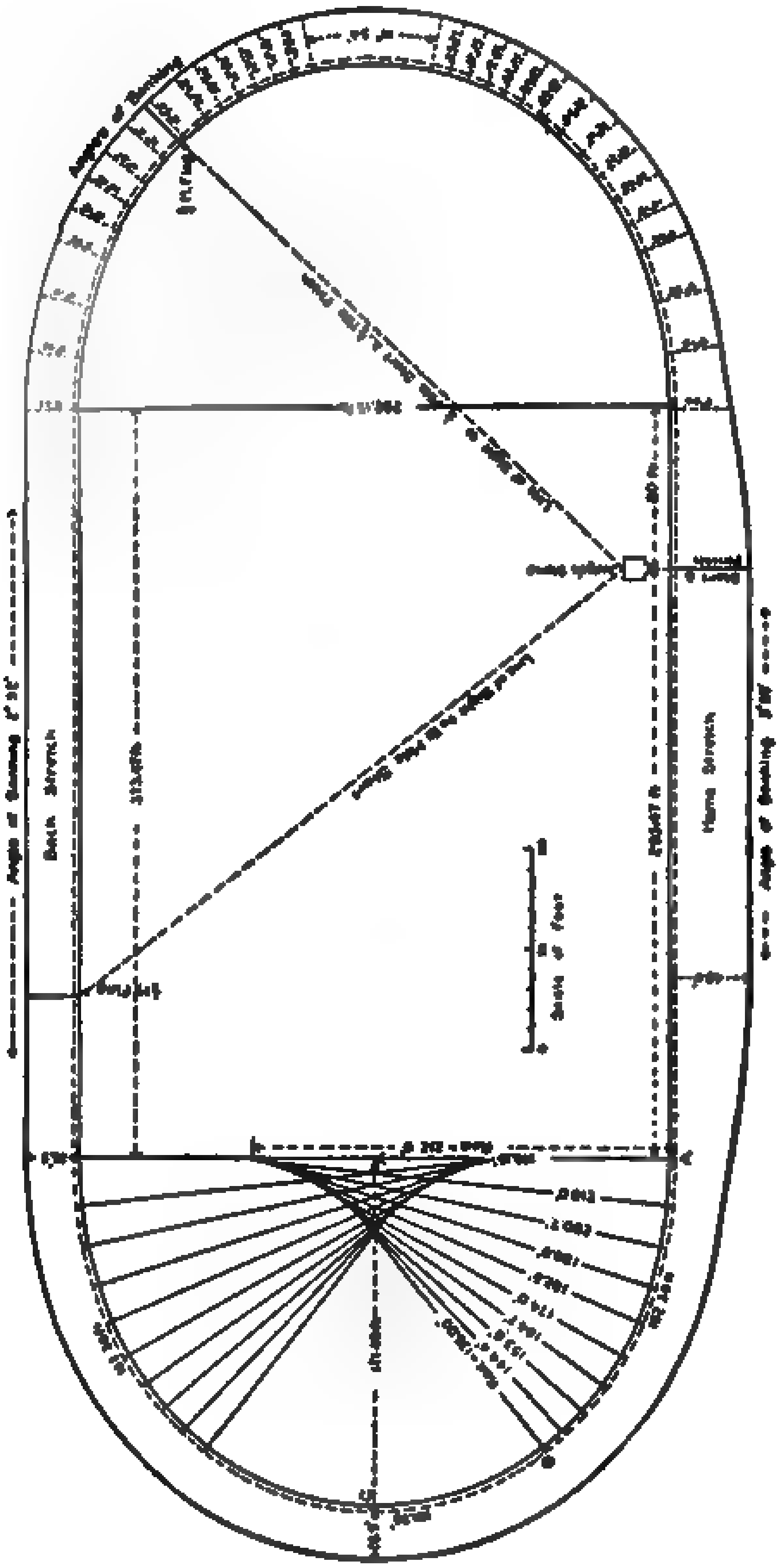

FIG. 186.—ONE-THIRD MILE TRACK AT MANHATTAN BEACH, LONG ISLAND, N. Y.

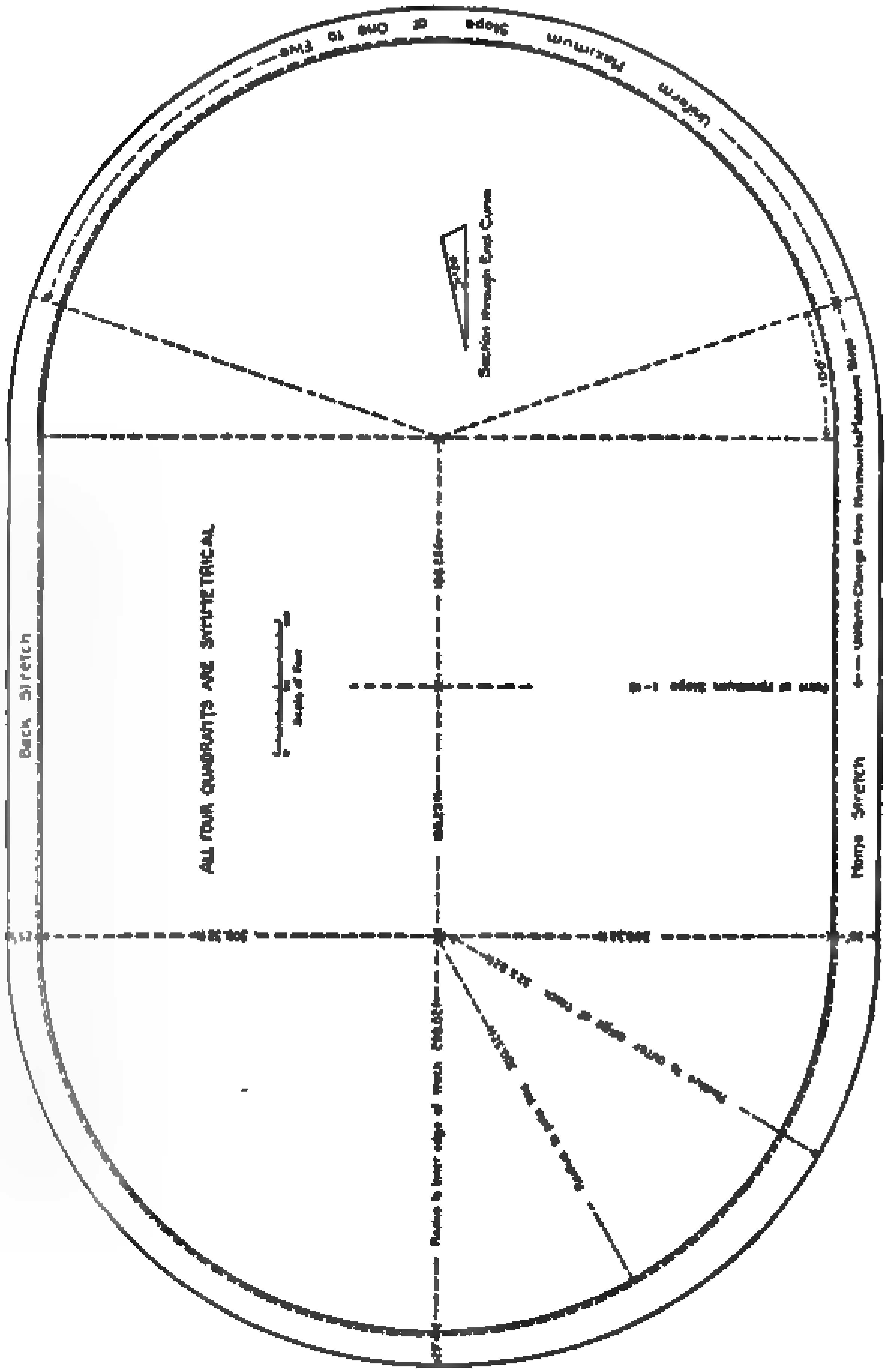

FIG. 107.—ONE-HALF MILE BICYCLE TRACK AT GARFIELD PARK, CHICAGO.

of the same ground plan as the Manhattan track except that the tangents were shortened and a higher banking was used.*

These examples represent the most advanced theory of the form of bicycle-race tracks, since almost all others have been built by carpenters or professional riders without reference to the principles involved.

995. Ideal Form. The length and the form of the track will depend upon the size and the shape of the area available. These factors will vary so greatly that they can not be considered in a general design; and hence it will be assumed that the area available is unlimited.

For obvious reasons the length should be an aliquot part of a mile; and the best authorities claim that on the whole a track having four laps to the mile is most preferable. Therefore a design will be made for a one-quarter mile track.

996. *Proportions of the Field.*—To determine the relation between the length and the breadth of the field of those tracks which may be considered as the best representatives of current practice, Table 65 was computed. A study of these data shows that a track to meet the requirements of current practice should have a field about twice as long as wide, or a width of field about one fifth of the length of the track. A field of these proportions will give a track affording the spectators a good view of all parts of the race.

TABLE 65.

PROPORTIONS OF FIELD REPRESENTATIVE OF THE BEST CURRENT PRACTICE.

Arranged in the Order of Roundness.

Ref. No.	Name of Track.	Length of Field.	Width of Field.	Ratio.	Length of Track.	Width of Field.	Ratio.
1	Garfield Park..	976.5 ft.	600 ft.	0.61	2640 ft.	600 ft.	0.23
2	Racine.	499.6 "	295 "	0.59	1320 "	295 "	0.22
3	Hawley †.....	519.6 "	275 "	0.53	1320 "	275 "	0.21
4	Waltham ‡....	709.0 "	300 "	0.42	1760 "	300 "	0.17
5	Manhattan. . .	715.5 "	295 "	0.41	1760 "	295 "	0.17
		mean		0.51	mean		0.199

* *Jour. Western Society of Engineers*, Vol. 4, p. 225–27.

† Recommended by Mr. C. E. Hawley, Sing Sing, N. Y., the recognized authority on bicycle tracks, in a private communication to the author.

‡ Same as the track at Louisville.

997. *Form of Curves.* The track should gradually change from the straight line to the maximum curvature in order that the rider may experience no lurch in going from the straight to the curved portions. If in Fig. 168 the full line *A B C D E* represents a portion of the pole line of a track consisting of semicircles connected by tangents, a racer riding in the direction indicated, upon arrival at *B*, the point of tangency, will not be able to change instantly from a straight path with an infinite radius to a curved path with a uniform finite radius, but will involuntarily take a curvilinear course having a uniformly decreasing radius. The dotted line of Fig. 168 shows the path involuntarily taken by the rider.

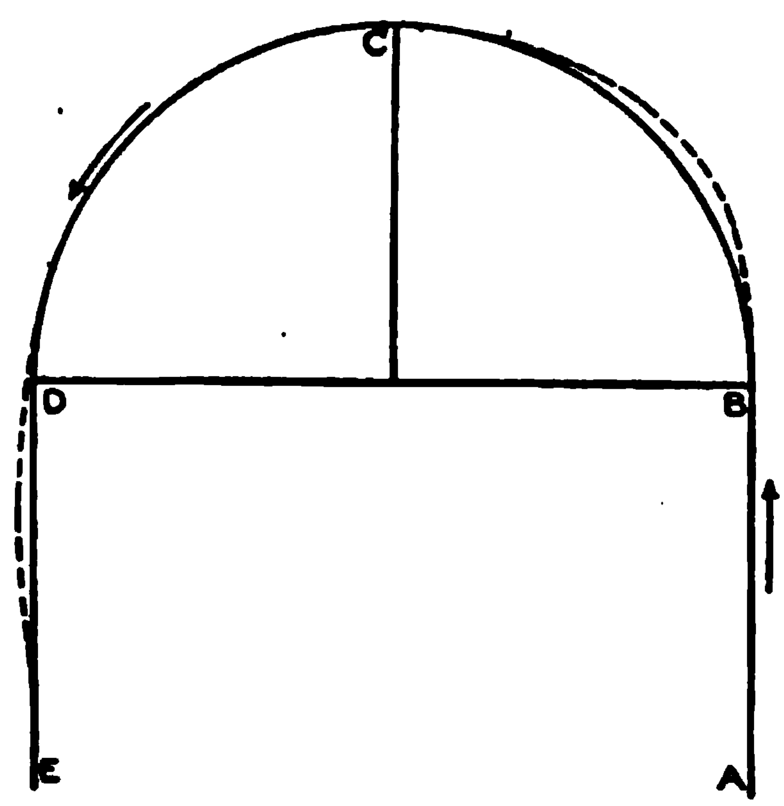

FIG. 168.

Similarly in entering a tangent from a curve, the rider will swing out from the pole line of the tangent in a curve of increasing radius. Since the distances are measured on the pole line, and since all excess distance ridden adds to the time of the race, there is a decided advantage in having the pole line of the same curvature as that of the path naturally taken by the rider. Further, the greatest ease with which a wheel can be guided around a curve of gradually varying radius also adds to the speed of the race.

Again, the outer edge of the track on curves should be higher than the inside, to neutralize the effect of centrifugal force; and this super-elevation should vary inversely as the radius of curvature. Since it is impossible to change instantly from flat tangents to banked curves, a track consisting of semicircles and tangents will

not permit the proper super-elevation of the outer edge, but if the tangent is connected to the circular arc by a curve of uniformly varying curvature, the banking required increases gradually from zero on the tangent to the full amount at the beginning of the circular arc.

This condition is approximated by joining the tangent and the circular curve by circular arcs of decreasing radii, as in the Manhattan track, Fig. 166, page 635; but this condition is fully and more simply met by using the transition spiral (see § 429).

Fig. 169, page 640, shows a one-fourth mile bicycle track each quadrant of which consists of a tangent 30 feet long, a transition spiral 160.18 feet long and a circular arc 139.82 feet long, making a total length of 330 feet for one quadrant or 1,320 feet for the complete circumference. The circular arcs may be laid out by any of the methods described for Horse-race Tracks in Art. 2, Chapter VII, pages 278–92. The transition spiral may be laid out in either of two ways, namely: (1) by deflection angles from the initial tangent and by chords measured along the curves; or (2) by offsets from the tangent prolonged. Table 66 and 67, page 641, give the data for laying out the spiral by the two methods just mentioned.

TABLE 66.

CHORDS AND DEFLECTION ANGLES FOR LOCATING THE TRANSITION SPIRAL FOR THE INSIDE EDGE OF A QUARTER-MILE BICYCLE TRACK.

Ref. No.	Point on Spiral.	Distance from the P. S. along the Curve.	Deflection Angle at the P. S. from the Initial Tangent.
1	P. S.	0.00 Feet	0° 00′
2	1	25.0 "	0° 16′.3
3	2	50.0 "	1° 5′.2
4	3	75.0 "	2° 27′.0
5	4	100.0 "	4° 21′.0
6	5	120.0 "	6° 15′.6
7	6	140.0 "	8° 30′.7
8	P. C. C.	158.47 "	10° 53′.7

The field of the track shown in Fig. 169 is 0.59 as wide as long, and is a little nearer round than the mean of the tracks in Table 65, page 637; but if the field were made narrower, the curvature would be sharper, and curves with a large radius are of more importance

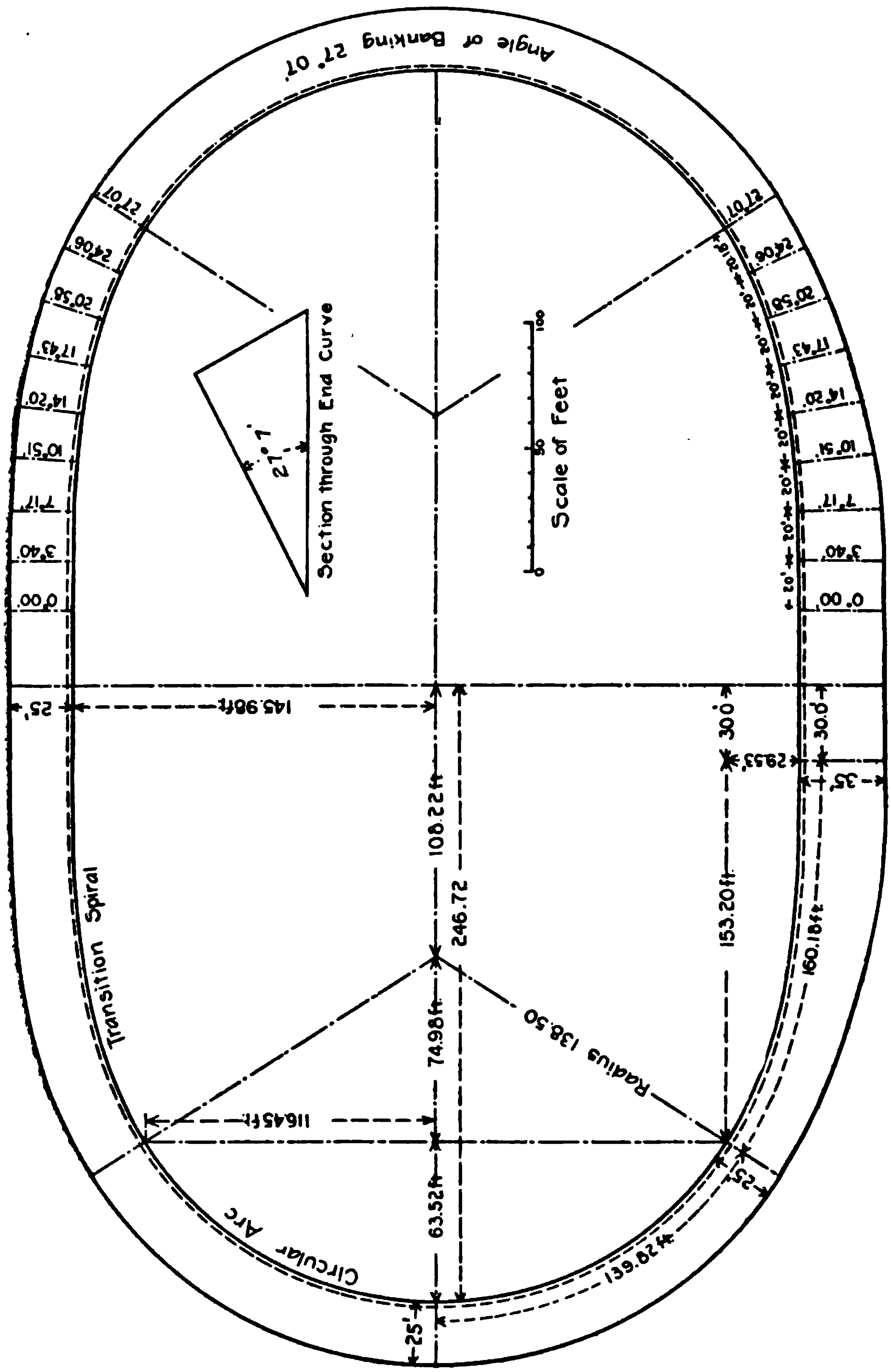

FIG. 169.—IDEAL ONE-FOURTH MILE BICYCLE-RACE TRACK.

than a narrower field. The above design meets all the requirements stated in § 992 and also possesses some important features new in bicycle-race track construction.

TABLE 67.

RECTANGULAR COORDINATES FOR LOCATING THE TRANSITION SPIRAL FOR THE INSIDE EDGE OF A QUARTER-MILE BICYCLE TRACK.

Ref. No.	Point on Spiral.	Distance from P. S. on the Tangent Prolonged.	Offset Perpendicular to the Tangent.
1	P. S.	0.00 Feet	0.00 Feet
2	1	25.00 "	0.12 "
3	2	49.98 "	0.95 "
4	3	74.88 "	3.20 "
5	4	99.48 "	7.57 "
6	5	118.71 "	13.03 "
7	6	137.18 "	20.55 "
8	P. C. C.	153.20 "	29.52 "

998. SUPER-ELEVATION. If a man attempts to ride a bicycle around a curve, the rider and the wheel must lean inward to balance the centrifugal force; and if the surface of the track is level transversely, the wheel will not be perpendicular to the surface and will tend to run in a curve, which may have a greater or a less radius than that of the track, and consequently increased attention and effort will be required in guiding the wheel. Further, if the inclination of the wheel is considerable, there is a tendency for it to slip on the surface. If the outside of the track is elevated on the curves so that the wheel is always perpendicular to the surface, then the wheel has a tendency to continue in a straight line, and only a minimum effort is required in guiding; and consequently the whole attention may be given to securing speed.

Equation (2), page 290, shows the relation that should exist between the super-elevation or banking, and the speed and the radius of the curve.* Having the design of the ground plan, the radius of

* Strictly speaking the R in this formula should not be taken as the radius of the pole line, but as the radius of the curve described by the center of gravity of the rider and the wheel, which will be a little less than the radius of the pole line owing to the inward inclination of the wheel and rider; but such refinement is unnecessary.

curvature will be known; but since the banking depends upon the velocity, the track must be designed for some particular speed. In deciding upon the velocity to be adopted, it is necessary to determine whether the maximum or mean velocity shall be employed. If the track is to be used chiefly for races ridden against time, the maximum velocity should be adopted; but if the track is to be used chiefly for miscellaneous racing, the super-elevation should be designed for the average velocity. To determine the practice in this respect, the banking of the more noted tracks will be investigated.

In the early tracks high banking seems to have been avoided for two reasons: first, because of a baseless prejudice against it; and second, because many of the races ridden in competition were so slow as not to require high banking. Recently the speed has increased, and motor pacing has become prevalent; and hence higher banking is more common.

The curves of the Louisville and of the Waltham tracks have a banking such that at a speed of a mile in 2 minutes and 53 seconds the wheel is normal to the surface. The super-elevation of the Manhattan track was computed for a speed of a mile in 2 minutes and 32 seconds. Fig. 166, page 635, shows the banking of this track, expressed in degrees with the horizontal. The curves of the Racine track, which have the same radii as the Manhattan track, are banked for a speed of a mile in 2 minutes and 26 seconds—a trifle higher speed than for the Manhattan track. The banking of the Garfield Park track was computed for a speed of a mile in 2 minutes. The angles of the super-elevation of this track are shown in Fig. 167, page 636. It is stated that Johnson in 1896 on this track, in making a world's record of a mile in 1 minute and 49 seconds, leaned slightly toward the inside of the track. Since the banking was figured for a 2-minute gait, the rider going at a speed of 1 minute and 49 seconds would be compelled to lean toward the center of the track to balance the centrifugal force, which shows in a crude way the agreement of theory and practice.

Many short wooden tracks have been constructed with very high banking. Notable among these is a sixth of a mile track opened in Springfield Mass., in July, 1900. The curves (apparently semicircles) are banked for a speed of a mile in 1 minute and 20 seconds, the inclination of the surface on the curves being 48°.

and on the tangents 30°—the steepest track known. This track is pronounced by racing men to be the fastest in the world.

A summary of the speeds for which the various tracks were constructed is shown in Table 68.

TABLE 68.

SPEED FOR WHICH THE BANKING OF DIFFERENT TRACKS WAS CONSTRUCTED.

Ref. No.	Name of Track.	Speed.	
		Feet per Second.	Time for 1 Mile.
1	Waltham *.........	30.53	2 min. 53 sec.
2	Manhattan.........	34.24	2 " 34 "
3	Racine.............	36.17	2 " 26 "
4	Garfield.	44.00	2 " 00 "
5	Springfield, Mass....	66.00	1 " 20 "

* Same as the track at Louisville.

999. It is obvious that the choice of the velocity to be used in computing the super-elevation depends upon experience and judgment, and not upon mathematical relations. If the track is to be used for motor racing without competition, the velocity should be high, perhaps 66 feet per second, or a mile in 1 minute and 20 seconds; but if the track is to be used for races of competition without motor pacing, this velocity should be about 44 feet per second, or a mile in 2 minutes.

The values shown in Fig. 169, page 640, were computed for a velocity of 48 feet per second, or a mile in 1 minute and 50 seconds. Should the speed vary materially from this value, the wheel will not stand exactly normal to the surface, and hence may have a tendency to slip; but the tires of a bicycle will not slip unless the angle between the plane of the wheel and the normal to the track is greater than the angle of repose. Experiments show that the angle of repose for a bicycle rubber-tire sliding on a dry cement sidewalk is 23° 15′, and practically the same value for a smooth dry wooden surface. For macadam, cinders, gravel, etc., the angle of repose is considerably more than the above. Therefore there will be no danger of the wheel's slipping, if the speed be increased until the wheel leans nearly 23° outside of the normal to the track, or if the speed be decreased until the wheel inclines nearly 23° inside of the

normal. For the track shown in Fig. 169, page 640, the first position of the wheel corresponds to a speed of a mile in 1 minute and 12 seconds, and the second to a mile in 4 minutes and 53 seconds. The former is the speed of the fastest steam-motor cycle, and the latter is lower than any probable bicycle race. Therefore if the super-elevation of the track shown in Fig. 169 is adjusted for a speed of 48 feet per second, or a mile in 1 minute and 50 seconds, it can be used for considerably faster races, and still be safe for slow races and amateur riding. However, it will not be possible to attain the highest speed unless the super-elevation is adjusted approximately for that speed, since otherwise part of the rider's attention and effort is required to balance his wheel.

1000. It is the practice of some designers to compute the banking for one speed, and then construct the track with an arbitrary, fractional part of the computed value. For example, the banking of the Manhattan track was computed nominally for a 2-minute speed, and then constructed with a super-elevation equal to 60 per cent of the computed value. The actual banking is that required by a 2 minute and 34 seconds speed.

1001. It has been proposed to make the surface of a bicycle-race track on curves concave as shown in Fig. 170. In other

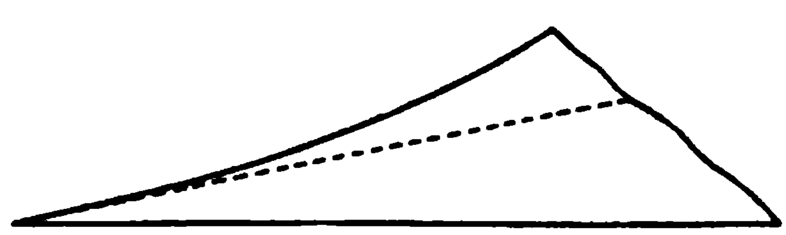

FIG. 170.—CONCAVE SURFACE OF BICYCLE-RACE TRACK.

words, it has been proposed to make the angle of inclination of the surface of the track greater at the outer edge than at the pole line. The claim is that such a surface would make it easier for one rider to pass another, since to accomplish this he must ride at a higher speed and hence would require a steeper inclination. This conclusion is wrong, since the effect of the increased radius of curvature almost exactly counteracts the effect of the increased velocity (see equation (2), page 290). It is also claimed that the concave surface would prevent a rider from flying off the tracks, should he momentarily lose control of his wheel. This advantage is not important, since the banking is sufficient of itself to prevent such an accident. However, the concave surface would be an advantage

on a track having low banking. A third objection to the concave surface is that it would be more expensive to construct. On the whole, a straight surface is probably the better.

The tendency to "fly the track" may be lessened by painting parallel guide lines on the surface of the track. This feature was used on the Manhattan track as described more in detail in § 1003.

1002. Materials of Construction. The surface of a bicycle-race track may be loam, clay, cinders, wood, or cement.

Most of the early tracks were constructed of either loam or clay. Such surfaces are cheap and easy to construct; but on the other hand, (1) the cost of maintenance is great, (2) high banking can not be used, and (3) moisture destroys temporarily the usefulness of the track. The Hampden Park track was constructed of clay covered with a thin layer of brick dust, and at one time was very popular, owing chiefly to its excellent surface.

A surface of cinders is very cheap and easy to construct, and is not affected by moisture; but cinders can not be used with high banking, and such a surface is expensive to maintain, and wounds received by a rider in falling often prove serious.

A well constructed wooden surface is very fast, and for this reason has been used in many short tracks, in which high banking is required. An example of such construction is the Colosseum track at Springfield, Mass. The surface consists of strips, one inch square, nailed to a foundation of 2″×10″ timbers. In-doors, where tracks are frequently constructed for temporary use, wood has decided advantages; but for out-door use wooden tracks are uneconomical, because of the destructive action of the elements.

In most of the larger tracks lately constructed, cement surfaces have been used. Such a surface is practically indestructible, and hence there is no expense for maintenance. Its usefulness is not destroyed by moisture, and any degree of smoothness may be obtained. Cement was used in the construction of the Waltham, the Louisville, the Manhattan, the Garfield Park, and the Racine tracks. The surface of the Manhattan track is most nearly ideal and for that reason will be described somewhat in detail. As is shown in Fig. 171, page 646, the embankment of the Manhattan track is composed of four distinct layers: 1, a gravel embankment; 2, an 8-inch layer of ash concrete; 3, a 3-inch layer of crushed granite concrete;

and, 4, a top layer of 1½ inches of cement mortar. The gravel was deposited in thin layers and thoroughly compacted by rolling. The ash concrete, whose purpose is to protect the gravel embankment from washouts and from injury by frost, consists of Portland cement and ashes in the ratio of 1 to 8 or 10. The 3-inch layer of granite concrete is composed of one part of sand, one part of Portland cement, and seven parts of crushed granite. The top layer consists of 1½ inches of mortar composed of one part Portland cement, one part sand, and two parts of powdered granite. Lampblack was

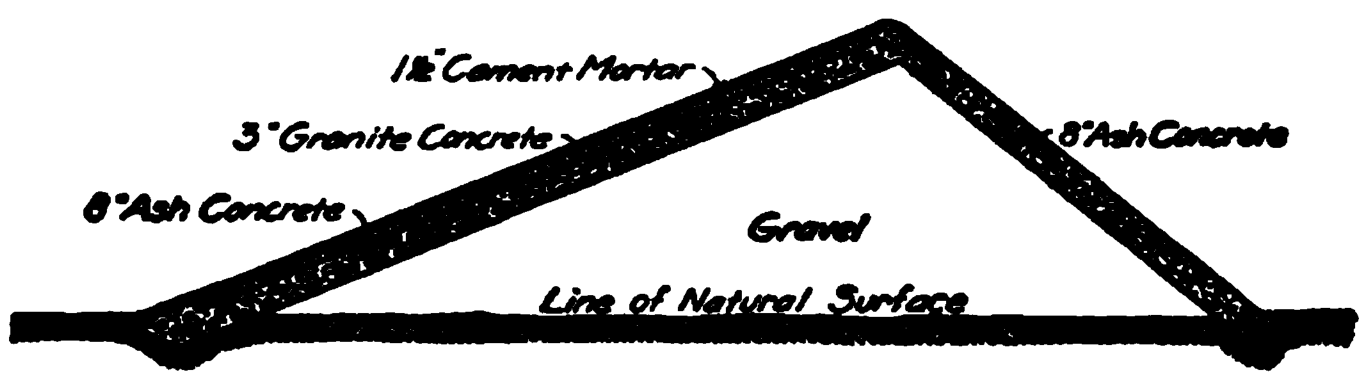

FIG. 171.—CROSS SECTION OF MANHATTAN BICYCLE-RACE TRACK.

mixed with the cement mortar to prevent the glare of the sun. The surface of the mortar was roughened by special tools to prevent the slipping of the tires. Special care was taken that the interstices between the blocks of concrete should not be so wide as to impart a vibration to the bicycle. The surface of this track has withstood the test of actual service, as well as the weathering of several years, and has proved itself very satisfactory.

1003. A novel feature of this track is the four parallel black guide-lines, each four inches wide, painted on the surface of the track. A racer riding at full speed with his head bent down over the handle bars does not notice that he is approaching the curve, and if he does not guide his wheel accordingly he will run off the track. The guide-lines warn him as he approaches the curves and thus prevent an accident.

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